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Dental microwear among prehistoric inhabitants of the Indian subcontinent: A quantitative and comparative analysis

Pastor, Robert F., Ph.D.

University of Oregon, 1993

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DENTAL MICROWEAR AMONG PREHISTORIC INHABITANTS OF THE INDIAN SUBCONTINENT: A QUANTITATIVE AND COMPARATIVE ANALYSIS

by

ROBERT F. PASTOR

A DISSERTATION

Presented to the Department of Anthropology
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

August 1993

APPROVED: John R Lukacs
DR. JOHN R. LUKACS

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Title: DENTAL MICROWEAR AMONG PREHISTORIC INHABITANTS OF THE INDIAN SUBCONTINENT: A QUANTITATIVE AND COMPARATIVE ANALYSIS

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This research investigates the qualitative and quantitative dental microwear of molar teeth from four archaeological sites in the Indian subcontinent: the mesolithic site of Mahadaha; the neolithic and chalcolithic periods of Mehrgarh; and the Bronze Age site of Harappa. These prehistoric South Asian populations are used to address three fundamental objectives: to establish the validity of dental microwear analysis of prehistoric human skeletal remains; to systematically characterize the dental microwear patterns of prehistoric South Asian populations and the associations with different diets, subsistence patterns, and levels of sociocultural complexity; and to provide inferences and predictions regarding prehistoric diets and subsistence patterns.

Shearing facets on replicas of permanent first and second mandibular molars were analyzed at high magnification (500x) with a scanning electron microscope. Qualitative comparisons and univariate and multivariate statistical procedures indicated significant differences between the archaeological groups, based principally on the density and size of microwear features, morphological characteristics of scratches, and enamel fabric.

The pattern of microscopic dental wear at Mahadaha consists of numerous narrow and some wide parallel scratches, combined with a few small pits, and is associated with the inclusion of fine grit to a diet of tough, fibrous wild plants and wild game. Chalcolithic Mehrgarh molars exhibit a relatively smooth polished enamel surface with very abundant large pits and wide scratches, which are associated with the consumption predominantly of grains processed with coarse groundstone tools. The microwear of the aceramic neolithic sample is intermediate, with more resemblances to the mesolithic sample, but also sharing some microwear and dietary affinities with the chalcolithic sample. A large amount of variation is present in the pattern of tooth microwear at Harappa, and is significantly influenced by dietary sex differences. Molars exhibit relatively large pits and long wide scratches, but moderate feature densities. This pattern is associated with a diet of predominantly soft, starchy processed grains, supplemented with wild plants and game.

A clear trend exists in the South Asian sample for increasingly coarse microwear features, and a lower rate of wear, associated with increased agricultural intensification. Increased variability for many microwear parameters and lower feature densities occurred during the Bronze Age, characteristics that are predicted for other prehistoric urban agricultural populations. The results of this study facilitate the production of inferences and predictions regarding paleodiets and subsistence systems of prehistoric humans and fossil hominids.

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DEDICATION

To Margaret, John, Dick, and Sisko

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CHAPTER I

INTRODUCTION

Research Orientation

The principle objective of my research is two-fold: (1) to test the association between dental microwear and prehistoric diets, as determined by archaeologically-derived data such as fauna, flora, and implements for food preparation; and (2) to construct a model by which dental microwear may be used to infer or predict the diet and/or food preparation practices in prehistory. The fully agrarian and archaeologically well-documented Harappan society will be used to define the dental microwear criteria for agricultural groups, establishing a standard for comparison with other South Asian prehistoric populations.

Of interest in my study is the paleodietary reconstruction of prehistoric cultures from the greater Indus and Ganga Valleys. While archaeologists have documented the technological and social aspects of ancient cultures at Mahadaha (Sharma et al. 1980), Mehrgarh (Jarrige and Meadow 1980), and Harappa (Allchin and Allchin 1982; Wheeler 1968), the paleopathology and microscopic features of human remains from these sites have, until recently, been poorly documented. At Mehrgarh this is because the human remains are just recently excavated and currently under study. Human remains from Mahadaha and Harappa were analyzed in the early 1960s and 1970s using now outdated analytical models and research techniques (e.g., Gupta et al. 1962), and many important facets of skeletal research were omitted completely (including systematic dental microwear analysis). In addition, prehistoric research in South Asia rarely includes close collaboration of archaeologists and physical anthropologists, although recent excavations at Harappa constitute a noteable exception (Dales and Kenoyer n.d.-a, n.d.-b; Meadow 1991). The

present analysis of newly excavated human remains from Harappa and Mehrgarh and reanalysis of remains from Mahadaha employs state of the art methods in paleoanthropology (dental microwear), and yields data capable of testing specific anthropological hypotheses and documenting the local history of diet and subsistence change in the Indus and Ganga Valleys.

Changes in population size, such as increased population density, often accompanied changes in subsistence pattern and food preparation practices of prehistoric populations. An overall decline in health status is often correlated with: (1) an increase in the incidence of endemic disease in a population; (2) an increase in urbanism; and (3) an increased reliance on agriculture. Also, the incidence of dental disease increases in human populations that rely increasingly on agriculture, whereas the rate of dental attrition decreases, in contrast to most hunter-gatherer populations.

The volume edited by Cohen and Armelagos (1984) surveyed changes in dental health, general health status, and demography accompanying the transition in subsistence pattern from hunting-gathering to agriculture among New and Old World cultures. Evidence was presented for an increase in the incidence of dental diseases, such as dental caries, as well as a decrease in the rate of dental attrition accompanying this cultural transition (Brace and Mahler 1971; Cohen and Armelagos 1984). However, no evidence was presented for a change in the amount or type of dental microwear, thus ignoring an additional analytical tool for determining diet and subsistence pattern. Also, the analytical models and paleopathological databases were more comprehensive for Native American skeletal series than for those of the Old World. My objective is to reconstruct dietary regimens of prehistoric greater Indus Valley and Ganga Valley populations.

Collecting baseline data on the changes in dental microwear pattern accompanying the adoption of agriculture and urbanism by peoples of the greater Indus and Ganga Valleys involves the analysis of teeth from four cemetery samples:

1. Mesolithic Mahadaha (MDH, 8000-1000 B.C.) geometric and non-geometric microlithic tools, hunting-gathering subsistence pattern, seasonal habitation areas (skeletal sample = 35);
2. Neolithic Mehrgarh (MR 3, 7000-6000 B.C.) pre- and proto-ceramic levels, microlithic blade industry, bone tools, stone and shell ornaments, hunting and incipient agricultural economy, small village settlement (skeletal sample = 113);
3. Chalcolithic Mehrgarh (MR 2, 4500 B.C.) wheel-made ceramics, microlithic sickles, copper ornaments, greater reliance on agriculture, larger, more sedentary village settlement (skeletal sample = 125);
4. Bronze Age Harappa (R-37, 2500-2000 B.C.) metal and ceramic technology, intensive dependence on agriculture, densely populated city, (skeletal sample = 97).

Biocultural Review

Human biology and cultural patterns of behavior are inextricably intertwined. However, artifacts and human skeletal remains from prehistoric archaeological sites traditionally have been considered separately. Within the past several decades, attention has been focused on greater collaboration between practitioners in these two fields, using increasingly advanced research tools and analytical methods. Rindos (1984) and Cohen and Armelagos (1984) have recommended that archaeological evidence for change in diets and subsistence patterns of prehistoric cultures be supplemented by evidence derived from the systematic analysis of skeletal remains, using novel research designs as well as more traditional methods of biological anthropology. As a result, the sophisticated analysis of prehistoric dental remains, including that represented by the present study, permits greater insights about culturally determined activities, such as subsistence pattern, food preparation and diet.

Dental microwear patterns have not been studied widely for prehistoric Homo sapiens. Several dental microwear analyses systematically investigated microscopic surface damage, such as scratches and pits, on prehistoric, fossil, and extant dentitions as a means of taxonomic allocation or for making nutritional and dietary inferences. Walker and colleagues (1978) suggested that differences in microwear can be used to distinguish if an extant or fossil animal was a browser or a grazer. However, microwear patterns have been shown to vary with features related to masticatory biomechanics in addition to specific aspects of diet (Gordon 1982; Ryan 1979b). Other authors, such as Peters (1982), contend that it may be difficult to directly associate microscopic striae with a particular type of food, food processing, or environmental cause. Considering these often opposing viewpoints, one must be cautious when making inferences regarding diet based on microwear analysis alone. Nevertheless, specific microwear patterns on wear facets of dental crowns are partially correlated with diet, feeding behaviors or food preparation techniques in early hominids, non-human primates, and prehistoric and modern human populations (Covert and Kay 1981; Gordon 1982; Grine 1981; Puech et al. 1983a, b; Shkurkin et al. 1974; Teaford 1991; Teaford and Walker 1984; Walker 1981).

To date, very few studies have applied scanning electron microscope analysis of dental microwear to the reconstruction of diet and subsistence in prehistoric human populations. These have been limited to prehistoric populations from Africa (Puech et al. 1983; Højgaard 1985), the Near East, and North America (e.g., Bullington 1991; Gordon 1986; Harmon and Rose 1988; Molleson and Jones 1991; Rose and Harmon 1986; Ryan 1980a; Teaford 1991; among others). Dental microwear studies using standard low power optical microscopy have also been undertaken on prehistoric populations from northwest North America and Australia (Fine and Craig 1981), or on early hominids and non-human primates (Covert and Kay 1981; Gordon 1982; Grine 1981, 1984, 1987; Teaford and Walker 1984; Walker 1981). Except for my own studies of Mahadaha, Mehrgarh and

Harappa dentitions (Pastor 1986, 1990a, 1990b, 1990c, 1991, 1992, n.d., Pastor and Johnston 1992), no intensive research on occlusal enamel microwear has been conducted on prehistoric or contemporary human populations of South Asia. Lukacs and Pastor (1988, 1990) reported on microscopic occlusal and interstitial striations present in a small sample of anterior and postcanine teeth from neolithic and chalcolithic Mehrgarh and Bronze Age Harappa, providing evidence for therapeutic probing and use of the teeth as a manipulative tool.

Teaford (1988a) provided a thorough and current review of SEM microwear studies which used experimental designs and museum collections of extant mammals. Initial interest in microscopic wear features on human and other mammal teeth wained during the 1950s and 1960s, due to the lack of proper analytical instrumentation and accurate replicating materials. However, development during the 1960s and the 1970s of the scanning electron microscope, together with high-resolution casting techniques, spurred renewed interest in dental microwear analyses (Teaford 1988a).

Much of the early analytical work on dental microwear was focused on characterizing the pattern of features on modern and fossil mammals other than humans. In general, these studies showed a regular pattern of microscopic features resulting from tooth-food-tooth or tooth-on-tooth contact, and varying with food consistency and masticatory biomechanics. Teaford (1988a) showed that hard-object feeders, such as Cebus apella or Pongo pygmaeus, exhibit a rough textured microwear pattern, with a preponderance of large pits, gouges and wide parallel scratches. Soft object feeders, such as the leaf-eaters Alouatta palliata and Gorilla gorilla exhibit a finer textured microwear pattern, with numerous small pits and many fine parallel scratches of varying orientation, often at right angles to each other. Primates with more variable diets, such as Pan troglodytes and Sivapithecus, showed intermediate types of microwear that were significantly different from the patterns of hard and soft object feeders (Teaford 1988a).

At the present level of analytical power, SEM microwear investigations can only recognize broad differences in the pattern of microscopic wear features and accurately associate them with dietary differences or specializations. For this reason, the few SEM microwear studies of prehistoric human samples have compared samples with very disparate dietary regimes. Uncertainty still exists regarding the contribution of food particles versus grit in the diet to dental microwear. The use of moderate-size samples of comparative material from South Asian cemetery sites, which vary chronologically and technologically, in conjunction with quantitative analyses will further elucidate the association between dental microwear and diet in prehistoric human populations.

A study such as mine, in which wear facet form and plane orientation is analyzed together with the characterization of the enamel microwear pattern, also requires a detailed analysis of occlusal attrition, with an emphasis on form and direction of surface wear as well as the degree of wear (see Chapter II for a discussion of dental wear terminology). In fact, a recent study by Teaford and Oyen (1989) shows that a relationship exists between rates of microscopic and macroscopic tooth wear. A brief review of the literature on dental attrition, especially as applied toward prehistoric South Asian populations, has been presented by Lukacs and Pastor (1990). A more detailed review of the dental attrition literature is undertaken in Chapter II.

A common objective of dental wear studies is to analyze the pattern, degree, and angulation of dental wear to infer specific aspects of diet, as well as to provide age assessments and insights regarding masticatory forces. These dental wear studies have shown that occlusal attrition is usually greater among hunter-gatherers than agriculturalists. This is because hunter-gatherers generally consume coarser foods, while agriculturalists eat more processed or refined foods (Hinton 1982; Lavelle 1969; Molnar 1971, 1972, 1982; Smith 1984). This difference in rate of occlusal wear appears to be associated with the actual number of chewing strokes required to reduce the food bolus before swallowing

(Roydhouse and Simonsen 1975; Teaford and Oyen 1989). Mandibular molar teeth usually exhibit greater buccal wear while the maxillary molars exhibit greater lingual wear. This relationship is a consequence of the slightly greater width of the maxillary arch, the greater height of the cusps on these respective surfaces of unworn molars, and lateral excursions of the mandible during shearing and grinding phases of mastication (Butler 1972; Hiiemae and Kay 1973). Differential wear also occurs on the cusps of the mandibular molars, with the buccal cusps wearing on both faces while lingual cusps wear on only a single face (Smith 1984).

Terminology

In the interest of clarity, I should note that the term diet, used in this study, refers generally to the types of food products consumed by a prehistoric group of people. Broad categories of food constituents include meat from domestic and wild animals, domesticated and wild varieties of grains, and raw or processed foodstuffs. Diet is not discussed in more specific terms of nutrient intake (Yesner 1980), due partially to the inadequacy of data from the archaeological record for specific kinds of foodstuffs consumed by the prehistoric populations of interest in this study. Subsistence pattern or activity (i.e., how food is obtained) is considered broadly with reference to particular prehistoric lifeways, such as hunting-gathering, incipient agriculture, and committed agriculture. Nutrition (i.e., how adequate the consumed food is for individual energy expenditure) was considered secondarily as it could be inferred from the results of the microwear analyses, from the archaeological data for diet and food processing, and from paleopathology data. Data regarding nutritional status, the condition of health as it is affected by the intake of foods and the utilization of nutrients (Caliendo 1979), of a prehistoric group were used where data on dental and skeletal markers (Huss-Ashmore et al. 1982) were available.

Research Objectives

My research program was designed to answer five primary questions and explore the broader implications of the answers. First, are the dental microwear patterns of Harappans significantly different from the microwear patterns of the mesolithic population of Mahadaha, or the neolithic or chalcolithic populations of Mehrgarh? Theoretically, the dental microwear of the committed agriculturalists from chalcolithic Mehrgarh should resemble that of the Bronze Age Harappa skeletal series more closely than does the dental series from neolithic levels at Mehrgarh, during which hunting and incipient agriculture were practiced. Conversely, quantitative measures of Mahadaha and neolithic Mehrgarh microwear are predicted to be similar, but with Mahadaha existing as an outlier because of the committed hunting-gathering lifeway and minimal input of processed cereal grains to the mesolithic diet. Comparison of dental microwear between these different series will further define the subsistence strategies practiced by each prehistoric group.

Second, it is hypothesized that microwear feature dimensions (primarily width) should increase in size, the types of features and their density should decrease, and the variability in overall microwear pattern should decrease with increasing sociocultural complexity. These hypotheses are based on the assumption that the diets of early hunter-gatherers (mesolithic and perhaps neolithic) would have been harder, more abrasive, and more variable than the diets of later urban agriculturalists. In other words, many types of tough or hard dietary constituents would have comprised the heterogeneous diet of hunter-gatherer groups. Conversely, the diet of urban agricultural peoples (chalcolithic and Bronze Age) is hypothesized to be less variable and more homogeneous. The diets of such groups would have been dominated one or two primary dietary constituents, probably soft, sticky foods made from processed cereal grains. In addition, variety of foods eaten would be more limited among prehistoric agriculturalists. New faunal evidence from Harappa

(Dales and Kenoyer, n.d.-b) has shown, however, that wild animals may have also been consumed by some residents of this urban site.

Third, do correlations exist between dietary intake and nutritional status of Harappan individuals, as revealed by dental microwear, and paleopathological indicators such as dental hypoplasia? Although dental microwear can only reveal what an individual consumed immediately prior to death, this period is as long as six months in cases of seasonally adjusted diets (Walker et al. 1978; Puech et al. 1983). Also, the association between a specific type of dental microwear and a particular disease condition may shed light on nutritional factors contributing to or ameliorating a disease state. For example, porotic hyperostosis, characterized by a syndrome of cranial lesions and thickening of the diplöe of the cranial vault, is initiated or exacerbated by chronic iron-deficiency anemia. It is also one of the principle paleopathological conditions resulting from thalassemia, an endemic disease in India since at least historic times. The dental microwear exhibited by such individuals may potentially help in the differential diagnosis of skeletal changes due to different anemic conditions (Ortner and Putschar 1985).

Fourth, are there recognizable differences in microwear pattern between Harappan individuals of different class status or of different sex? For example, remains of several females recovered recently from Harappa, associated with decorative jewelry, are presumed to be of high status (Dales and Kenoyer, n.d.-b). Analysis of the dental microwear of these individuals may reveal if differential dietary treatment is accorded to these individuals. Finally, is there any evidence for the origins of vegetarian dietary specialization at Harappa, based on an exclusively herbivorous type of microwear pattern? These research questions and the associated hypotheses are discussed from the perspective of the research results in Chapter VII.

Several operational (null) hypotheses have been formulated as guidelines in this dental microwear analysis:

H-1: The dental microwear pattern of fully agrarian Harappan society does not differ significantly from that of technologically less developed prehistoric cultures of South Asia.

H-2: The dental microwear pattern of the Indian subcontinent remains unchanged over time despite the change in diet and food processing technology accompanying agricultural intensification.

H-3: The dental microwear patterns of Harappans and of individuals from chalcolithic Mehrgarh do not differ significantly by sex or class status (by social class as determined from funeral practice) despite emergent class structure.

H-4: No association exists between dental microwear and nutritional status, or health status, of the Harappan population or of the earlier populations despite greater reliance on agricultural subsistence systems over time.

Significance

This project is significant for several reasons. First, a systematic analysis of dental microwear and attrition has never been applied before to skeletal series from the Indian subcontinent, or from South Asia in general. As such, results from this study fill a gap in the knowledge of the biological anthropology of prehistoric South Asian peoples.

Second, this study advances the knowledge of prehistoric dietary variation between archaeological sites, sociocultural classes, and sexes. Subsistence patterns inferred from dental microwear will supplement the knowledge from the archaeological record, consisting predominantly of subsistence artifacts, burial goods, zoological, and botanical evidence. Also, additional information will be obtained on diets and food preparation practices of each culture as well as the diachronic and geographic changes for these. The interest of American archaeologists in the diets and subsistence patterns of ancient civilizations of the

Old World has a long history. As observed by Fairservis (1975:251), "-- in planning to excavate, the French look for likely places to find temples, the Germans seek palaces, the British head for citadels, and the Americans inevitably find kitchens."

Third, results of this research have relevance for paleohominoid dental variation studies. Dental and gnathic elements are the most numerous remains available for fossil hominoids, and have been used historically by investigators in functional analyses of occlusion, taxonomic classification, and paleodietary and paleoenvironmental reconstructions. More recently, comparative analyses of dental microwear have been used to refine the models derived from earlier studies. The results of my research provide analogues for functional comparisons with early hominoid populations, and provide inferential data for the reconstruction of early hominoid paleodiets.

Finally, relevant models for dental microwear derived from this research are useful in the study of paleodiets among prehistoric human populations in other parts of the world. Such models can be used to design studies of existing skeletal collections as well as of newly excavated human remains. The continuation of dental microwear research on prehistoric cemetery sites in South Asia and elsewhere in the world will yield insights on shifts in plant and animal usage over time, and on transitions in prehistoric diet and subsistence systems.

Organization

A review of the relevant literature on dental attrition and dental microwear is presented in Chapter II. The section on attrition includes subsections on dental wear terminology, methods of analyzing tooth wear, and the use of attrition to determine diet, skeletal age, and nonmasticatory behavior, as well as its role in producing a helicoidal wear plane. The second section on dental microwear includes subsections on occlusal movement and facet production, and a review of microwear analyses focused on fossil and extant

hominoids and other mammals, as well as prehistoric human populations. Within Chapter III, discussion is focused on the excavation history, location, chronology, archaeology and physical anthropology of the four archaeological groups from which tooth samples were obtained for comparative study. These include the sites of mesolithic Mahadaha, neolithic and chalcolithic Mehrgarh, and Bronze Age Harappa.

The materials and methodological procedures used in this research are discussed in Chapter IV. Sections are provided on the materials and techniques for casting dental impressions and replicas, the optical analysis of wear facets, SEM analyses, metric data collection, qualitative analyses of microwear patterns, and the statistical analyses of microwear feature dimensions, counts and frequencies. Results of the qualitative and quantitative analyses are presented in Chapters V and VI, respectively. The micrographs from individual specimen fields are presented in Chapter V, while all tables and figures for the raw data and results of the statistical analyses are presented in Chapter VI. The results of the qualitative and quantitative analyses are discussed in Chapter VII, and the conclusions are presented in Chapter VIII.

CHAPTER II

REVIEW OF LITERATURE ON DENTAL ATTRITION AND MICROWEAR

Introduction

The following literature review summarizes previous work on both microscopic and macroscopic dental wear. The first section provides an overview of macroscopic dental wear, more commonly known as attrition, and its development as a field of scientific inquiry. Attention in this section is devoted to several areas of historical interest: (1) dental wear terminology, (2) attrition as a method for skeletal ageing, (3) the various techniques developed for assessing tooth wear, (4) its recognition as an indicator of diet and subsistence strategy, and (5) its use as an indicator of the manipulative use of the teeth. I also discuss the historical interest in a helicoidal pattern of occlusal wear. The second section consists of a detailed review of the literature on development of analytical methods in dental microwear and on studies of fossil and extant mammal microwear. This discussion is subdivided into five topical sections: (1) historical interest in dental microwear, (2) masticatory biomechanics and facet production, (3) microwear analyses focused on fossil and extant mammals, (4) dental microwear of fossil and extant hominoids, and (5) qualitative and quantitative microwear of prehistoric human populations.

Dental Wear Terminology

Campbell (1925:129) was one of the first investigators to make the distinction between abrasion and attrition as determinants in tooth wear. Campbell considered attrition to be caused by "teeth striking or running against each other, while abrasion was due to

"the presence of gritty material in food." However, Leigh (1925:184) made no such distinction, considering attrition to represent the "gradual wearing away of the hard parts of the teeth through the physical and physiological agencies of mastication of food," as well as through the mastication of narcotics. Klatsky (1939) also used a very restrictive definition of abrasion to consist of only pathological wear caused by friction of the tooth surface with a 'foreign body', such as a pipe, labret or even a toothbrush. As he defines attrition, it would actually encompass both macrowear and microwear of teeth due to tooth-tooth and tooth-food contact during normal mastication. But Moorrees (1957:129) states that attrition is produced by the frictional wear of the teeth, while abrasion is due to abrasive substances in the food. Dahlberg and Kinzey (1962, after Ryan 1980) also treated attrition as due to tooth-tooth contact, and believed the result was enamel polishing. Furthermore, Dahlberg and Kinzey considered abrasion to be the loss of enamel due to abrasive contaminants in the diet, which produces various types of scratches and pits that polishing is able to obliterate.

More recently accepted definitions for tooth wear have been elucidated by Pindborg (1970) and by Hiiemae and Kay (1973). Attrition, which can be considered to be a form of macroscopic wear, is produced usually by tooth-on-tooth contact after food has been softened, with approximal and occlusal surfaces coming into close or actual contact during the later phase of mastication (Hiiemae and Kay 1973; Pindborg 1970; Ryan 1979b). However, Hiiemae and Kay (1973:53) suggest that repeated transitory contact "between the teeth through a thin film of food and associated material" may also produce attrition resulting in the wearing of enamel on the ridges or slopes of cusps of the post-canine tooth row. Microscopic wear in the form of striations "orientated sub-parallel to the direction of relative tooth movement" is an additional characteristic of attrition (Hiiemae and Kay 1973:53). Abrasion can be considered a form of microscopic and macroscopic tooth wear (e.g., wear facets) produced by tooth-food contact. In other words, abrasion is produced

by the passing of the food bolus, containing dietary grit, or of foreign materials between occlusal surfaces of opposing teeth, usually during the masticatory process. More specifically, abrasion is produced at the point of "minimal gape (maximal approach to occlusion)" when pulping and crushing of food occurs between cusp tips of post-canine teeth on the active side of the jaw (Hiiemae and Kay 1973:51) The microwear pattern resulting from abrasion is usually characterized by polished and pitted surfaces (Ryan 1979b) and macroscopically as blunting of the cusps, loss of enamel and cavitation of the dentine as a result of puncture-crushing (Hiiemae and Kay 1973). Based on experimental evidence (Ryan 1979a, 1979b), Ryan suggests that polishing is the result of two factors: "(1) an increased amount of crushing; and (2) the action of fine striations being worn away by repeated linear movements" (1980:34). Also, the morphological characteristics of Phase I striae may be more obvious than Phase II striae because the latter sometimes become pitted by grinding that occurs during the Phase II stage of jaw movement.

Erosion has been described as a superficial loss of dental hard tissue by a chemical process which does not involve bacteria (Pindborg 1970; Eccles and Jenkins 1974). Eccles and Jenkins (1974) emphasize that it is difficult for a dental practitioner to differentiate between the effects of erosion and abrasion on the enamel of patients, because they both frequently target the labial and buccal surfaces. However, idiopathic behavior such as chewing aspirin tablets or consuming large volumes of citrus fruit, which may lower the ph of saliva, usually produces unmistakeable and dramatic erosion of tooth enamel (Eccles and Jenkins 1974; Sullivan and Kramer 1983). Bulemia and anorexia are also known to cause acid erosion of tooth enamel. Eccles and Jenkins (1974) also note the possibility of individual variation in degrees of resistance of enamel to erosive action, much as with intrapopulational variation in caries resistance. Perhaps it is premature to assume that the hardness of enamel, due to such factors as enamel decussation pattern, is invariant within a

species, let alone within a population. This could have implications for the interspecific and interpopulational comparison of the degree of attrition and microwear.

The modern concept of attrition/abrasion as 'tooth tissue loss', which is accepted by some current dental researchers and by the dental profession (e.g., Williams and Woodhead 1986), considers attrition as a mechanism rather than as a physical condition. Based primarily upon a western perspective of dentistry, foodstuffs normally occurring in the diet are not thought of as contributing factors to the mechanisms of dental attrition. The term 'tooth tissue loss' is used to encompass three components or mechanisms of tooth wear. These conditions are: "erosion, a chemical process involving dissolution, or chelation of enamel constituents at a near-neutral $_p$h; abrasion, the physical removal of tooth substance by agents introduced into the mouth, (e.g., toothbrushes and dentifrices); and attrition, a physical process whereby tooth surface is removed by the movement of the teeth against each other, possibly with an abrasive substance intervening" (Eccles 1982, after Williams and Woodhead 1986). Ryan (1980) emphasizes that the line of demarcation between attrition and abrasion is not well defined because of investigators' different usage and definitions for these two terms, and the often different conclusions for the same wear pattern. For example, Davies and Pedersen (1955:41) used the term attrition to describe the rounded wear on Australian Aboriginal anterior teeth as being due to prolonged mastication. But Van Reenan (1964:39) attributed the same phenomenon to nondietary use of the teeth or abrasion. Van Reenan apparently felt that rounded non-occluding incisor surfaces were evidence for this abrasion. Such a difference of opinion has also been expressed for the macroscopic wear involving hominid dentitions. For example, considerable controversy erupted between Brace (1964, 1967, 1975) and Wallace (1975) over the rounded incisor wear in Neanderthals, especially the specimen La Ferrassie I. Generally, the problem with the inexact use of tooth wear terminology is summarized in the following statement by Ryan (1980:18): "A fundamental problem, then, arises from the use

of the terms attrition and abrasion as broad definitions for patterns of wear. Although attrition is suggested to be related to the processes of mastication, the resulting wear pattern is difficult to define accurately. Likewise, employment of the word abrasion for nonmasticatory tooth use does not adequately describe the resulting kinds of wear patterns related to the use of the teeth for purposes other than chewing." Furthermore, some investigators (e.g., Hiiemae and Kay 1973) consider the processes of both abrasion and attrition to be intimately associated with the mastication of food. Consequently, Ryan (1980) recommends the use of descriptive terms to describe specific features or patterns of wear: striations, polishing, pitting, microflaking, gouges and patches. He feels that each pattern can then be associated with a specific dental activity. This would appear to be the prudent approach, and one that is accepted by most investigators of dental microwear, albeit often using even fewer categories to describe the microwear features. Use of the term attrition may still be more appropriately applied as a description of macroscopic tooth wear, because of the longstanding precedent established by earlier workers.

In the present study, the terminology of Campbell (1925) and Moorrees (1957) was adopted with modifications for distinguishing the discussion of macroscopic and microscopic dental wear. This simplified dental wear terminology is as follows:

1. Dental wear = Attrition = Macroscopic wear
2. Dental microwear = Microscopic wear

No further distinction will be retained between wear and microwear with regard to mechanisms for altering, scoring, or reducing enamel on the tooth crown. For example, recent studies have shown that tooth-tooth wear can lead to characteristic microwear features as well as gross wear of occlusal surfaces. As discussed in Chapter V, additional descriptive terms similar to those recommended by Ryan (1980) were used in the qualitative analyses of dental microwear.

Dental Wear

Within the past several decades, investigators have focused considerable attention on the tooth wear of prehistoric and living human populations, fossil and extant nonhuman primates, and fossil hominids as a means of determining:

1. temporal and geographical differences in diet and subsistence strategies (Brothwell 1963b; Campbell 1925; Devoto et al. 1971; Hall and German 1975; Hinton 1981; Janis 1984; Lavelle 1970; Leigh 1925; Lunt 1978; McKee and Molnar 1988; Molnar et al. 1983; Molnar et al. 1989; Pastor and Johnston 1992; Puech 1979, 1984; Richards 1984, 1985; Robinson 1954, 1972; Scott and Turner 1988; B.H. Smith 1984; P. Smith 1972; Turner and Machado 1983; P.L. Walker 1978; Weidenreich 1937);
2. age related wear patterns (Butler 1972; Dahlberg 1960a; Hall and German 1975; Kieser et al. 1983; Klatsky 1939; Leigh 1925; Lovejoy 1985; Miles 1963, 1978; Molnar 1971b; Nowell 1978; Richards and Brown 1981; Tomenchuk and Mayhall 1979);
3. the effects of culturally related behavior patterns (Berryman et al. 1979; Blakely et al. 1984; Borgognini Tarli et al., 1989; Brace 1975; Brown 1991; Brown and Molnar 1990; Carlsson et al. 1985; Dahlberg 1963b; Fernández-Jalvo and Bermúdez de Castro 1988; Formicola 1988, 1991; Formicola and Repetto, 1989; Kennedy et al. 1981; Kieser et al. 1985; Larsen 1985; Lukacs and Pastor 1988, 1990; Molnar 1971a, 1972; Power and O'Sullivan 1988; Roydhouse and Simonsen 1975; Schour and Sarnat 1942; Schulz 1977; Taylor 1963, 1984; Turner and Cadien 1969; Ubelaker et al. 1969; Wallace 1974, 1975; Williams and Woodhead 1986; Wolpoff 1971);
4. jaw movements (e.g., Hall 1976; Hinton 1982; Osborn 1982; Tobias 1980); and

5. sex differences (e.g., Formicola and Repetto, 1989; McKee and Molnar 1988; Molnar 1971b).

The earliest tooth wear studies (e.g., Campbell 1925; Klatsky 1939; Murphy 1959) centered on the role that attrition played in disease and occlusion. Later studies focused on the relationship between occlusal wear and the influence of diet and culture or from the manipulative use of the teeth (e.g., Barrett 1977; Cybulski 1974; Ubelaker et al. 1969; Wallace 1974, 1975). More recently, investigators have focused attention on different subsistence bases and their contribution to the loss of occlusal enamel (e.g., Richards 1984; Molnar et al. 1989; B.H. Smith 1984; P.L. Walker 1978). Several studies have been at least partially devoted to the development of analytical techniques for assessing the degree and form of dental wear (Behrend 1977; Butler 1972; Hall 1976; Hall and German 1975; Lavelle 1970; McKee and Molnar 1988; Miles 1963; Molnar 1971a; Molnar et al. 1983; Murphy 1959; Scott 1979a; Scott 1979b; Tomenchuk and Mayhall 1979; Teaford and Oyen 1989a).

Method for Skeletal Ageing

Investigators have long been interested in tooth attrition as a method for estimating the chronological age at death of human skeletal remains, especially in the absence of other skeletal indicators such as the morphology of the pubic symphysis or endocranial and ectocranial suture closure. Age estimation by tooth wear also is occasionally used as corroborative evidence when these other indicators of chronological age are present. However, some investigators (e.g., Bass 1987) are skeptical of relying on tooth attrition as an indicator of age at death, because significant individual variation exists for tooth attrition within and between populations. Many ordinal scales for scoring tooth wear have been introduced in the past 50 years (B.H. Smith 1984). Methods of grading attrition used by early investigators (e.g., Davies and Pedersen 1955; Klatsky 1939; Leigh 1925) used a

simple four-stage system, which coarsely measured the loss of occlusal enamel from the surface of a tooth. Although not necessarily developed for estimating age at death, most scoring methods (e.g., Scott 1979a, B.H. Smith 1984) have been modified versions of either Murphy's (1959) or Miles' (1963) eight-stage tooth wear evaluation systems. Brothwell (1965:69) also presented a graphically oriented age classification of tooth wear based on his study of a large sample of teeth from a medieval British population. While not as comprehensive as the Miles or Murphy methods, it has been recommended by various authors of osteology texts (e.g., Bass 1971) and remains in use by some investigators (e.g., Hall et al. 1986) as an aid in skeletal age assessment.

Miles (1963) compared chronological (relative) age of an individual, based on molar tooth eruption schedules, with the functional age of a molar tooth as determined from the observed rate of tooth wear. This method of age assessment assumes a six year interval between formation and eruption of successive molars. To use this system, a primary sample of molar teeth must first be derived from a sample of immature individuals, who can be assigned ages based upon dental development standards. This independently-aged sample can then be used as a baseline of known ages from which to compare successively older groups of individuals in the population, based upon increasingly greater molar wear. The degree of tooth wear is determined by comparing an individual specimen with graphical depictions of the eight stages of wear for first, second and third mandibular molars. These stages of wear are in turn based on four features of tooth attrition, which form a series of progressively greater expression as wear increases: (1) polished enamel, which is present only in the first stage of wear; (2) occlusal enamel wear facets; (3) exposed dentine; and (4) the formation of secondary dentine or exposure of the pulp cavity. However, Miles cautions that accuracy decreases with material older than age 30, for which extrapolation is necessary. Also, this method is not readily applicable to other skeletal collections unless the subsistence pattern or level of cultural development can be assumed

to be similar to the Anglo-Saxon material used in his study (Miles 1963). The Miles method has been used successfully by Nowell (1978) and other investigators.

The system for scoring dental attrition devised by Murphy (1959) includes the entire tooth row of both jaws. His study of an Australian aboriginal skull collection is one of the first systematic analyses of dentinal exposure in the human dental arcade. However, Murphy was more interested in showing the patterns of exposed dentine that are possible in human dentitions, and in the progression of cusp attrition and dentine exposure in a tooth class, than in producing a method for age estimation. A specific association between tooth wear and chronological age at death of the individual is not provided in Murphy's paper. In order to assess age at death of an individual with Murphy's system, one must match the patterns of dentine exposure observed on the occlusal surfaces of the teeth with standardized drawings that are keyed to scores between zero and nine.

Pal (1975) reported the results of an attrition study on a large sample of permanent molars from Hindu, Moslem and Oriya crania collected near Calcutta in 1866. He used a slightly modified version of Murphy's system to examine the association between age and dentine exposure. As in other studies, the degree of dentine exposure increased directly with age. Mandibular molars exhibited more severe wear for a particular age class than did maxillary molars, a phenomenon for which no satisfactory explanation could be found.

Attrition patterns as a progressive function of age were investigated by Butler (1972), but his purpose was to identify changes in the occlusal plane throughout the life of the individual rather than the assessment of age itself. Other investigators (e.g., Lovejoy 1985; Tomenchuk and Mayhall 1979) have found that within a population the degree of tooth wear and age are highly correlated, and the rate of wear appears to increase with age. While use of occlusal attrition as an estimate of skeletal age has long been held in disfavor by some investigators, it has recently been revived as a technique that can provide precise age assessment for both prehistoric and contemporary humans in the absence of other

skeletal indicators (Cook 1984; Kieser et al. 1983; Lovejoy 1985; Lovejoy et al. 1985; Miles 1978; Molnar et al. 1983; Walker et al. 1991), and as part of a systematic multifactorial assessment of age at death within and between populations (Lovejoy et al. 1985). A recent article by Walker and colleagues (1991) showed that the combination of crown height and occlusal angle measurements in a multiple regression model explained significant amounts of the variation in molar wear due to age. Application of tooth wear-based age assessment methods must also consider interpolation problems caused by individuals with considerable antemortem tooth loss, as well as account for intrapopulational sex-based differences in tooth wear that may be produced by socioeconomic, dietary or nonmasticatory factors (Lovejoy 1985; Walker et al. 1991). Nevertheless, these and other osteologists would likely concur with Miles' statement that "in archaic populations, tooth wear probably provides the best indicator of age if it can be used systematically" (1978). It is certainly clear that reliable and accurate age assessment is possible, provided that baseline data is gathered from younger individuals with unworn or slightly worn dentitions, as was suggested by Miles (1963), and as long as the resulting data is applied only to intrapopulational comparisons.

Analytical Techniques for Assessing Tooth Wear

Several analytical techniques for ranking or scoring tooth wear have been introduced in the past three decades, some of which have relied on modifications to either the Murphy (1959) or Miles (1963) methods for assessing the amount of dentine exposure (e.g., Lavelle 1970; Molnar and Molnar 1985; Richards and Brown 1981; Scott 1979a; B.H. Smith 1984). Other investigators have devised unique methods for assessing the form and plane of wear (Butler 1972; Hall 1976; Hall and German 1975; Molnar 1971a), or developed quantitative methods of assessing the level of molar wear by measuring cusp height (Molnar et al. 1983; Tomenchuk and Mayhall 1979; Walker et al. 1991), the relative

area of dentine exposure (Behrend 1977), the volume of dentine exposure (Teaford and Oyen 1989a), or the size of occlusal wear facets of molars and premolars (McKee and Molnar 1988). Although this surfacing of different analytical techniques reflects a continued interest in intra- and interpopulational differences in dental attrition, the lack of standardization and acceptance of at least a smaller set of protocols continues to hinder the development of dental attrition as a field of investigation, as well as diminishing the possibility of uniform comparisons between studies done by different investigators.

Following is a review of several of these analytical techniques, including those of Molnar (1971a) and Scott (1979a) which are used in this study. Molnar (1971a) devised an ordinal scale for assessing the degree of wear, and the form and orientation of the wear plane of both anterior and posterior teeth. Degree of wear is based on the amount of dentine exposure exhibited on the occlusal surface of the tooth, and is graded on an ordinal scale of 1 to 8, with a higher score representing a more severely worn tooth. In turn, the tooth is assigned a numerical score corresponding to the orientation of the wear plane. For example, a score of 1 represents a tooth with a natural or unworn form of occlusal plane orientation, while a tooth assigned a wear orientation score of 3 possesses a wear plane that is orientated buccally (i.e., the lingual edge of the occlusal plane is higher than the buccal edge). Finally, the general form of the wear plane is scored also on a 1 to 8 scale. Molar tooth wear is scored on the basis of categories such as fully cupped, half-cupped , or horizontal wear form. Mean values for any aspect of the scale and for each tooth type may then be computed for use in interpopulational comparisons. However, the ordinal nature of the values limits comparisons to assessement with nonparametric statistical analyses. In practice, these scales are not easily applied and the shape and angle of wear are only generally representative of the complex form that the occlusal surface of a tooth may take. However, the Molnar scoring method is still one of the few to account for both degree and inclination of wear.

The ordinal wear scale devised by Scott (1979a, 1979b) places more emphasis on grading the amount of enamel remaining on the occlusal surface of a tooth. The inherent assumption is that as wear progresses, a tooth will possess less occlusal enamel and exhibit increasingly greater amounts of dentine. Although the emphasis of the Scott method is reversed from the Molnar technique, the intent is much the same. However, with Scott's method the tooth is divided into quadrants, each of which is scored separately on an ordinal scale of 1 to 10. For example, a totally unworn quadrant would be assigned a score of 1, while one exhibiting only small wear facets without dentine exposure would be assigned a score of 2. The latter is comparable to a score of 2 on the Molnar scale. A Scott score of 0 represents missing data or a quadrant that could not be scored. Wear scores for each quadrant are summed, producing an overall wear score for the tooth which can vary from 4 to 40. According to Scott (1979b), this method more closely approximates an interval scale and produces a more precise and robust measure of total tooth wear than the Molnar (1971) method. The method also produces fewer tied ranks and explains more of the variance by contributing to lower confidence limits. Because of its greater control of variability, a Scott score produces increased interpopulational discrimination with principal axis analysis (Scott 1979b).

Other investigators (e.g., Benfer and Edwards 1991; McKee and Molnar 1988; Richards 1984) have also used principal axis analysis as a tool for data reduction and to indicate trends within the patterns of data relating to intra- and interpopulational variation in rates and patterns of tooth wear. Lavelle (1970) and Lunt (1978) calculated mean rank (or area) differences between successive teeth in the molar row in order to allow comparison of different samples based on rates of tooth wear. Patricia Smith (1972) undertook a similar analysis, but computed correlations between rates of wear and different populations.

Wear plane angle has been assessed by Butler (1972), Hall (1976), and other investigators as a means of determining the buccolingual shape of the occlusal plane across

the tooth row. The technique involves placing the edge of a protractor across the highest points of the cusps of two antimeres. This places the plane of the protractor at a relatively normal angle to the mesiodistal axis of the tooth being measured. The angle of the occlusal plane is simply measured as the angle of divergence from a vertical axis. However, this method can only determine the relative angle of inclination, since it accepts the assumption that the original occlusal plane was horizontal. A more accurate representation of the change in angle of the occlusal plane from the original unworn state would be to measure the angle of the occlusal plane relative to a plane projected through the cemento-enamel junction (CEJ) of the tooth, with the underlying assumption that this plane approximates the original unworn occlusal plane. Such a technique would also be useable on isolated teeth. Although angle assessment techniques provide a more quantitative measure of wear plane orientation than the Molnar (1971a) method, it is difficult to obtain reliable measurements and the often complex form taken by the occlusal surface, as well as the CEJ, ensures that angle assessment is only a general measure of wear plane orientation.

A method developed for quantitatively measuring the height of cusps on the occlusal surface of plaster casts of molar teeth was introduced by Tomenchuk and Mayhall (1979) and refined by Molnar and his colleagues (1983). The technique requires the modification of a standard dial-indicated depth gauge by replacing the steel probe with a plastic probe, and attaching a plastic bushing to allow the barrel of the instrument to rest on the apices of the mesiobuccal, mesiolingual and distobuccal cusps. Tomenchuk and Mayhall (1979) adapted the depth gauge used in their study to accept a ball-tipped steel probe and wide steel base. Cusp height is measured as the difference in height between a plane projected tangent to these three cusps and the intersection of the mesiobuccal groove and the central groove, in the case of the mandibular molars. Design limitations of the instrument used in both studies existed, primarily in the size of the probe, which was too large to fit in the deep recesses of the sulcus of some teeth. Another limitation not

mentioned by these investigators is in the use of plaster casts, that often possess a sill or dam of casting material across the opening of the sulcus. In such cases, only relative cusp height is being measured, although the error would probably be minimal if considered across an entire sample of casts. Another problem reported for the depth gauge method is its inability to differentiate between very worn teeth, in which the cusps had been entirely removed and large amounts of dentine exposed (Molnar et al. 1983). Both studies relied on a normalizing index designed to compensate for allometric differences in tooth size by dividing the cusp height by the product of the mesiodistal and buccolingual diameters. Using simple linear regression to plot the tooth wear index against chronological age of individual Eskimos, Tomenchuk and Mayhall (1979) were able to derive a predictive model of the level of tooth wear for an Igloolik Eskimo population.

A potentially useful technique for assessing dental attrition with a continuous scale variable was introduced by Behrend (1977). Severity of wear is determined by the surface area of exposed dentine relative to the occlusal surface area, as measured from enlarged photographs of the occlusal plane of the teeth of prehistoric individuals. Multiple regression analyses indicated that the area scores were more sensitive indicators of tooth wear than scores based on Murphy's (1959) ordinal scale. An innovative advance in analyzing tooth wear patterns, offered by McKee and Molnar (1988), involves the identification of wear facets on the occlusal surfaces of premolars and the first and second molars. The area of each facet was calculated by digitizing tracings made from enlarged photographs of the occlusal surface of each dental cast. Data reduction and pattern recognition was facilitated through the use of principal components analysis. They admit to the subjective factor inherent in observing the outlines of occlusal wear facets, but they fail to recognize the problem of facets with very oblique angles that may be difficult to discern when the tooth is oriented at only a single angle to the viewer. Also, determination of the

true surface areas of oblique facets will always be skewed, since the plane of each facet should be parallel to the plane of the film in order to accurately assess the surface area.

The area covered by wear facets showed a great deal of inter-dependence between occluding teeth, suggesting that maxillary and mandibular wear patterns share a common cause. Principal components analysis revealed four groups of wear patterns that contributed to considerable variation in the gradient of wear between M1 and M2 of the Australian Aborigine sample (McKee and Molnar 1988). The authors offer an explanation of a biomechanical gradient of mesiodistal loading along the occlusal surfaces of the tooth row. They also suggest a score of intervening factors that must be considered when attempting to statistically analyze dental attrition patterns. While many factors contribute to overall tooth wear, the unusual results of this study may have been due in part to the methodological problems of facet recognition and measurement mentioned above.

An additional technique for quantitatively assessing the level of tooth wear in extant monkeys was introduced recently by Teaford and Oyen (1989a). The technique employs a reflex measuring microscope and computer software for digitizing and calculating the volume of dentine exposure on occlusal surfaces. Although still in the experimental stage, this refinement in technique also allows the assessment of the depth of exposed dentine, such as in dentinal pits, and it has the potential to more accurately determine the pattern and shape of tooth wear.

A recently published technical report (Conry 1992) described the potential usefulness of computerized profilometry for collecting and analyzing three-dimensional information on occlusal wear, as well as dental morphometrics. Although the technique requires a considerable amount of computer memory and is time consuming, it proved superior to the traditional caliper-based measuring techniques when systematic error was compared between methods and between independent investigators.

Tooth Wear as an Indicator of Diet and Subsistence

Many studies of dental attrition have been conducted with the goal of determining the diets of extinct and extant primates (e.g., Janis 1984), the subsistence patterns and diets of prehistoric human populations (Brothwell 1963; Dahlberg 1963; Hinton 1981; Lavelle 1970; Leigh 1925; Lunt 1978; Molnar 1971a, 1971b, 1972; Molnar et al. 1989; Richards 1984; B.H. Smith 1984; Turner and Machado 1983; P.L. Walker 1978) or with the intent of determining the contribution of dietary factors to dental attrition among living people (Barrett 1977; Davies and Pedersen 1955; Klatsky 1939; Molnar et al. 1983; Williams and Woodhead 1986).

Longstanding proponents of research on dental attrition of prehistoric and extant human groups are Molnar (1971a, 1971b, 1972) and his colleagues (Molnar et al. 1983; Molnar et al. 1989). Their studies have ranged from broad perspectives on tooth wear and its functional relationship to various cultural practices (Molnar 1971a, 1972), to longitudinal studies of tooth wear in extant Australian Aboriginal populations (Molnar et al. 1983), and to cross-sectional investigations of several prehistoric and historic populations of Australian Aborigines and Native North Americans (Molnar 1971b; Molnar et al. 1983; Molnar et al. 1989). In his review of the functional use of teeth in prehistoric populations, Molnar (1971a, 1972) emphasizes several links between tooth wear and cultural behavior that have been observed by various investigators. For example, even among prehistoric populations the severity of tooth wear appears to decline with increasing agricultural development or urbanization (Brothwell 1963; Campbell 1938; Davies and Pedersen 1955; B.H. Smith 1984). However, Leigh (1925) noted that prehistoric Sioux, who were Plains hunter-gatherers, exhibited less tooth wear than the Arikara, a sedentary population who also inhabited the Plains. Out of the four prehistoric groups investigated by Leigh, the three sedentary agricultural populations evinced more tooth wear than the single hunter-gatherer (Sioux) group, possibly as a result of large amounts of introduced grit derived

from the use of groundstone implements. The contradictory results reported by Leigh are perhaps attributable to sampling error, the lack of systematic control for age, or other contravening factors.

Also frequently cited in the literature is the relationship of attrition not only with particular constituents of the diet and the amount of preparation of food, but also with the eating habits of a particular group of people. Any one of these cultural factors can be implicated in the ingestion of abrasive or tough materials in a diet that may otherwise not contain such materials. For example, Collins (1932:460) reported that the meat of sea mammals and fish consumed by unacculturated Eskimos often became contaminated with sand, contributing to severe tooth wear among both males and females. This has also been reported by Lovejoy (1985) for the prehistoric Libben population, a North American hunter-gatherer population in which fish formed a major constituent of the diet. Phillip Walker (1978) calculated the surface area of the exposed dentine from enlarged occlusal photographs of mandibular molars of prehistoric individuals from the Santa Barbara Channel. He found that the early prehistoric population at Canada Verde on Santa Rosa Island showed a relatively high rate of dental attrition. This is probably due to a diet with a high concentration of shellfish, fish and sea mammals, but he suggests that this dental wear may also be attributed to acquisition of grit in the food if these people were drying their food in the sand. In a similar fashion, the dried shark meat used as a staple 'bush' ration by Maoris required such a great amount of masticatory effort, because of its toughness, that it undoubtedly was a contributing factor in the amount of tooth attrition observed by Taylor (1963). Other often overlooked factors contributing to tooth wear in many populations are: the constant addition of supplementary but tough, fibrous, hard or gritty foods to the diet; chewing quids of plant materials such as milkweed, coca leaves, tobacco or yucca; the use of the teeth to crack bones in order to extract the marrow; or the ingestion of an entire small animal, bones and all, after it has been pounded into a mush (Molnar 1972). With regard

to the latter practice, Hinton (1982) presents paleofecal evidence, and interproximal and occlusal tooth wear data, which indicate that Archaic populations from the Tennessee Valley consumed wild vegetal and animal foods with little or no preparation. For example, coprolites found in cave deposits revealed entire small mammals with hides and bones intact, indicating that animals were sometimes consumed whole.

Sex-specific variation in attrition has occasionally been reported for prehistoric and historic human populations. These differences are often attributed to dietary differences that may be at least partially due to task specialization, especially among hunter-gatherers. For example, Molnar (1971b, 1972) suggests that during food-collecting activities, women of a hunter-gatherer population frequently sample taste the different wild and often tough and fibrous foods that they encounter. Similarly, the men of these groups frequently have first , and occasionally exclusive, access to meat acquired during hunting forays. Similar observations have been made for contemporary African pygmies and Bantu (Walker and Hewlett 1990:385). The principal axis analysis by Richards (1984) of the dental wear of two Australian Aboriginal populations revealed both interpopulation and sex differences. Richards suggests that more vigourous mastication required by the tougher and less desirable pieces of meat in the diet of Narrinyeri females may have contributed to their greater rate of posterior tooth wear than the Narrinyeri males. But a nonmasticatory function may have contributed to the more rapid rate of wear of maxillary central incisors among Kauma females when compared to males. The author suggests that the observed interpopulation differences may be due to dietary differences, as well as to possible variations in craniofacial and dental morphology.

A greater degree of tooth wear was also observed by Molnar and colleagues (1983) for male members of a living Australian Aboriginal population, who were undergoing acculturation. Although all members of the group were experiencing change in their diet under settlement conditions, older male members often consumed wild plants and animals

during their frequent forays into the bush, and this supplementation of the settlement diet with tougher and more fibrous foods presumably contributed to their greater dental attrition. But this population as a whole still possessed more severely worn dentitions than other more sedentary Aboriginal populations, who consumed a less transitional diet. Apparently, the practice by the acculturating Aboriginal population of baking flour cakes in hot ashes may have introduced enough grit into the diet to produce abnormally worn teeth. No significant sex differences were reported by Molnar and colleagues (1989) in a thorough analysis of the Murray Black skeletal collection of prehistoric and relatively recent Australian Aborigines. The same study revealed significant variation in degree of tooth attrition among several groups of the purportedly homogeneous skeletal collection. Riverine based subsistence differences may have been responsible for the observed variation in tooth wear (Molnar et al. 1989). Greater tooth wear has been reported among prehistoric female California Indians (Molnar 1971b), a situation due to either dietary differences or to task-specific activity. In addition, Tomenchuk and Mayhall (1979) observed greater dental attrition among Eskimo men. However, Turner and Cadien (1969) observed a distinctive form of tooth wear (pressure-chipping) among male and female high Arctic Eskimos, Aleut and Indians from northern Canada, although the former group exhibited a much higher frequency of "severe crushing and or flaking of the crown surface of one or more teeth" (Turner and Cadien 1969:303). Apparently, the poorer subsistence base of the high arctic Eskimo influenced both men and women alike to chew the bones of game and fish as a supplement to their diets. Davies and Pedersen (1955) also found very little difference in attrition between living male and female Eskimos from Greenland. A similar situation was observed by Kieser and colleagues (1985) for a living population of Lengua Indians from Paraguay. Many prehistoric populations also exhibit little variation in tooth wear between male and female individuals. For example, Lunt (1978) reported no significant sex differences in wear rates for her population of prehistoric Danes, nor were

any significant differences observed by sex for the prehistoric Libben population (Lovejoy 1985).

Other features of tooth wear, such as occlusal wear plane angle or shape, have been shown to vary significantly between prehistoric populations possessing contrasting subsistence bases (Molnar 1971a; B.H. Smith 1984). For example, a prehistoric hunter-gatherer population from the Central Valley of California, dated to 2000-3000 years B.P., exhibited generally oblique wear planes, but also a more rapid rate of wear than prehistoric agricultural populations (B.H. Smith 1984). Smith (1984) also noted that hunter-gatherers exhibit a more even distribution of wear on the cusps of molars than agriculturalists, with the former possessing a relatively low wear plane angle even in severely worn specimens. These differences in occlusal wear plane angle are due to a general difference in food consistency: much coarser foods in the diet of the former while the agricultualist diet contains more processed or refined foods (Hinton 1982; Lavelle 1969; Molnar 1971a, 1972). This difference in wear plane angle and rate of occlusal wear appears to be associated with the actual number of chewing strokes required to reduce the food bolus before swallowing (Roydhouse and Simonsen 1975; Teaford and Oyen 1989).

Tooth Wear Caused by Manipulative Use of Teeth

Activity induced markers of behavior in the teeth of human populations have long been of interest to dental anthropologists (e.g., Barrett 1977; Berryman et al. 1979; Blakely and Beck 1984; Borgognini Tarli et al. 1989; Brown 1991; Brown and Molnar 1990; Cybulski 1974; Formicola 1988, 1991; Formicola and Repetto, 1989; Larsen 1985; Leigh 1925; Lukacs and Pastor 1988, 1990; Milner and Larsen 1991; Power and O'Sullivan 1988; Schulz 1977; Turner and Cadien 1969; Wallace 1974, 1975; Willey and Ubelaker 1976; Ubelaker et al. 1969). Cultural behaviors that have the potential to induce such marks most often involve the use of the teeth as tools, or for other non-masticatory

purposes. For example, Leigh (1925) suggests that the unusual amount of lower incisor attrition among Zuni men may have been due to a sex-specific craft activity, in which a tool was held in the mouth. Activity induced tooth wear can vary in position and extent on the tooth surface and within the dental arch. Anterior teeth of prehistoric and living pre-industrial populations may exhibit wear ranging from minimal loss of enamel on their labial surfaces to severe loss of occlusal enamel, or to scoring in the form of grooves on the occlusal or interstitial surfaces. Manipulative use of the posterior teeth frequently produces attrition in the form of severe degradation of the occlusal surfaces or as a noticeable interproximal groove, described as "a transverse furrow of variable shape worn into the mesial or distal surface of a tooth at or near the cement-enamel junction" (Lukacs and Pastor 1988:378).

A recent review of behavioral alterations of teeth (Milner and Larsen 1991) stressed the wide variety of archaeological groups from which interproximal grooves have been reported. For example, interproximal grooves were found on the teeth of Arikara Indians (Berryman et al. 1979), Bushman and South African Negro (Wallace 1974), Irish populations (Power and O'Sullivan 1988), California Indians (Schulz 1977) and other early to late prehistoric North American Indian populations (Ubelaker et al. 1969), among prehistoric populations from Baluchistan (Lukacs and Pastor 1988, 1990), in neolithic and later populations from Ireland (Power and O'Sullivan 1988), and among early Upper Paleolithic human remains from Italy (Formicola and Repetto 1989). In most cases, little evidence exists for a postmortem cause of interproximal grooving, such as through intentional mutilation as part of a burial ritual. In many cases, interproximal grooving can be attributed to the insertion of a dental probe (e.g., toothpick) as a therapeutic or palliative measure (Berryman et al. 1979; Borgognini Tarli et al. 1989; Ubelaker et al. 1969), although this is not always the case (Formicola and Repetto 1989; Lukacs and Pastor 1988, 1990; Schulz 1977). For example, Ubelaker and colleagues (1969) found a high

association of interproximal grooves with alveolar resorption, which is produced by periodontal disease, and with interproximal caries. Often, an inflexible, cylindrical dental probe of small diameter is indicated by the groove morphology, as well as its position on the tooth and in the dental arcade. In most cases, orientation of the groove axis changes from an angle normal to the mesiodistal axis of anterior teeth to a more oblique angle, when grooves are found on posterior teeth (Berryman et al. 1979; Ubelaker et al. 1969). The latter situation derives from the necessity for inserting an inflexible dental probe between the molars with the probe angled "inward and backward from the lip region" (Ubelaker et al. 1969:146). However, the angle of insertion between the molars is occasionally perpendicular to the mesiodistal axis of the teeth. For example, this was observed for several individuals from the Neolithic phase at Mehrgarh (Periods IA and IB, MR3 excavation area), and may have been associated with production of sinew or fiber (Lukacs and Pastor 1988). This study and others (e.g., Power and O'Sullivan 1988) also employed a scanning electron microscope at a relatively high power of resolution to identify the presence of scratches oriented parallel to the axis of the groove. As other studies have shown through low power light microscopy (Berryman et al. 1979; Borgognini Tarli et al. 1989; Formicola and Repetto 1989; Ubelaker et al. 1969; Wallace 1974), the presence of such striations is indicative of a dental probe or fibrous material having been passed back and forth between the molars, rather than in a twisting motion. A recent analysis by Brown and Molnar (1990), using macroscopic analysis of Australian aboriginal dentitions and ethnographic film footage, has provided additional evidence for this kind of scenario, although it has also been a subject of controversy (Brown 1991; Formicola 1991).

Grooving has also been observed on the occlusal surfaces of anterior and posterior teeth in prehistoric populations. For example, all adult individuals in a prehistoric population of California Indians exhibited abraded grooves on the occlusal as well interproximal surfaces of anterior teeth (Schulz 1977). All of the grooves were small in

width and oriented labiolingually, but their position on individual teeth was quite variable. In addition, both isolated and bilaterally aligned grooves were observed, as well as the coupling of approximal and occlusal loci. These factors in combination with a lack of association of grooving with caries, plus considerable ethnographic evidence, lead Schulz to conclude that the tooth grooving was produced as a result of a task activity involving the preparation or use of cordage made from plant fibers. Cybulski (1974) noted a similar phenomenon for a prehistoric population of Indians from Prince Rupert, British Columbia, except that only the lower anterior teeth of a small number of adult females possessed such grooves. Craft specialization is indicated here, especially the preparation of plant fibers during the practice of weaving baskets, a craft for which the Tsimshian people were well known during historic times. Similar features, labelled "striated furrows," were found on anterior and posterior teeth of an Italian Mesolithic population (Borgognini Tarli et al. 1989). The authors were equivocal as to causation, attributing these features to friction resulting from the mastication of vegetable fibers or tendons, but admitting that extra-alimentary or para-alimentary factors could also be implicated. A survey of a large number of prehistoric and historic western Great Basin dentitions by Larsen (1985) revealed a small proportion of mandibular and maxillary anterior teeth with linear grooves on their occlusal surfaces. All grooves possessed a uniformly small width and mesiodistal orientation, and grooving was only found on male dentitions. Low power scanning electron microscope (SEM) analysis revealed the presence of fine striations within the trough of the grooves and parallel to the groove axis. As with other studies that used ethnographic analogies, Larsen concluded that the grooved teeth represent male-dominated craft specializations, the most likely of which are either the production of cordage from plant fiber or the preparation of sinew for bowstrings.

A relatively uncommon form of dental abrasion was observed on the lingual and facial surfaces of anterior teeth of prehistoric populations from the Northwest coast of

Canada (Cybulski 1974) and from Baluchistan (Lukacs and Pastor 1988, 1990). Cybulski (1974) attributes the flattened and shiny areas of abrasion on the labial surface of anterior teeth to the wearing of labrets (lip plugs) by possibly high-ranking members of either sex. The macroscopic and microscopic (SEM) study by Lukacs and Pastor (1988) revealed the presence of lingual surface abrasion on anterior teeth from neolithic levels at Mehrgarh, Baluchistan, and several possible etiologies were considered. The anterior teeth (maxillary and mandibular incisors and mandibular canines) of four individuals exhibited a smooth polished labial surface, often with abrasion severe enough in magnitude to have erased well defined marks of linear enamel hypoplasia. In addition, lingual surface abrasion "sufficient enough to remove all enamel and expose secondary dentine" was observed on upper and lower incisor teeth of one of the four specimens (Lukacs and Pastor 1988:391). The authors provided a survey of the wide range of occupational and feeding behaviors that involve the use and subsequent wear of the anterior teeth, as documented in ethnographic accounts Although incisal enamel chipping and facial abrasion co-occur in the dentitions at Mehrgarh, the fine facial polishing of maxillary anterior teeth argues against the use of the teeth for the retouch of stone tools, an etiological concept proposed by Gould (1968:45) for the unusual anterior tooth wear observed in aboriginals of Western Australia and the Great Plains. Other possible causes of facial abrasion of maxillary teeth considered by the authors included the "stuff and cut" method of eating meat (Brace 1975, Ryan 1980), grasping the mouthpiece or bit of a bow drill (Lous 1970, Merbs 1973), splitting reed or bamboo stalks, and wearing labrets (Cybulski 1974). Very fine microscopic striations observed on the facial surfaces of these anterior teeth exhibited orientations which either paralleled the horizontal hypoplastic lines or were transverse to the sagittal plane of the tooth. At least three of these types of manipulative use of the anterior teeth considered by Lukacs and Pastor (1988) could be implicated as etiological factors for the facial surface wear pattern of Mehrgarh teeth. The unusual lingual surface wear may have been caused

by the use of the anterior teeth in hide preparation, much as was practiced by Eskimo women (Molnar 1972). However, the authors conclude that ethnographic documentation is needed for the use of the anterior teeth during craft activities or eating by living peoples of the subcontinent, together with an assessment of the associated microscopic features of wear, in order to conclusively explain aberrant abrasion patterns.

Davies and Pedersen (1955) have suggested that severe planar attrition observed on the occlusal tooth surfaces of male Greenland Eskimos may actually be an indirect result of a cultural behavior, specifically kayak paddling and other strenuous activities during which individuals are reported to excessively clench and grind their teeth. However, the severe attrition may also be attributable to hard and tough constituents in the diet of non-urbanized Eskimos, to tooth hardness, or to fluorosis (Davies and Pedersen 1955). As stated earlier, the lack of sex differences in attrition of Aleut, Eskimo, and northern Indian dentitions lead Turner and Cadien (1969) to offer a dietary rather than manipulative hypothesis for the distinctive type of severe attrition observed. In this case, an unusual type of tooth abrasion, in which the enamel and dentine of the crowns exhibit crushing , fracturing and splintering, is attributable to the practice of crushing bones in order to extract the marrow. Other investigators (e.g., Molnar 1972) believe that the severe attrition observed among Eskimo men is due to activities such as holding the reigns of a sled with the teeth, and among traditional female Eskimos to such craft activities as preparation of hides during the manufacture of skin clothing.

Intentional dental mutilation has occasionally been observed among prehistoric populations from the North American and other continents (Milner and Larsen 1991), and among some living groups of people. Technically, this practice cannot be categorized with the manipulative use of the teeth, but rather as a separate category of cosmetic alteration. For example, Willey and Ubelaker (1976) describe several Archaic period burials from Texas which exhibit pronounced V-shaped notches and grooves on the labial and occlusal

surfaces of anterior teeth. They attribute these features to culturally prescribed tooth filing, similar to the more commonly observed cases from Mexico and from Mesoamerican-influenced late prehistoric sites in the southwestern, midwestern and southeastern United States. Cosmetic alteration of anterior teeth has also been reported in prehistoric skeletal remains from Bhimbetka in central India (Kennedy et al. 1981). In a paper by Blakely and Beck (1984), a model is proposed by which intentional mutilation may be differentiated from manipulative use of the teeth in prehistoric populations. Although they use currently outdated definitions of abrasion and attrition, the model possesses useful and testable criteria, especially their contention that intentional dental mutilation rarely changes with age (although it may decrease due to normal attrition), whereas "erosion" from task-related activities should increase with age. Another criteria that appears to have a sound basis in fact is the notion that intentional dental mutilation should be found in only a small portion of a population, often among those of high rank or class status, whereas wear attributable to manipulative use of the teeth would be exhibited by a larger proportion of the population, who practice a similar craft specialization.

Helicoidal Wear Pattern

The helicoidal pattern of tooth wear is completed on the third molar and is elicited by advanced wear, producing a'twisted' antero-posterior occlusal plane across the posterior dental arcade. The term helicoidal was first used to describe this pattern by Ackermann (1941, after Tobias 1980). In fact, the shape of the helicoidal curve has sometimes been compared with that of a propellor or to a single strand of the DNA double helix. Many investigators have commented on the presence of this differential plane of wear between successive molars in the posterior dental arcade and between maxillary and mandibular molars (Butler 1972; Campbell 1925; Hall 1976; Hall and German 1975; Keiser et al. 1985; Leigh 1925; McKee and Molnar 1988; Osborn 1982; Roydhouse and Simonsen

1975; B.H. Smith 1983, 1986; Tobias 1980). For example, Leigh (1925) observed that in the human dentition the wear plane of maxillary teeth is often oriented lingually, while mandibular teeth possess buccally oriented wear planes. However, the 'compound' wear plane observed by Campbell (1925) in Australian Aboriginal dentitions involves differential direction (buccolingually) of wear between the first and third molars of the same dental arcade. In other words, the wear plane of the lower first molar possesses a buccal slope while the third molar possesses a lingually sloped occlusal plane. This dental wear pattern later became known as the helicoidal pattern (Ackermann 1941). It is generally measured by the amount of exposed dentine produced by tooth wear (Hall 1976) in combination with the angle and direction of the wear plane (B.H. Smith 1986).

Arch width, degree of attrition, and possibly tooth implantation (lingual axial tilt) have all been implicated by one or more investigators as major factors in the production of the helicoidal pattern of tooth wear. For example, Hall and German (1975) showed that attrition plays a significant but not exclusive role in development of the helicoidal plane. The role of tooth wear resulting from tooth-to-tooth contact (attrition), rather than from contact of the tooth with the food bolus (abrasion), has also been implicated in the development of a helicoidal plane of wear (Roydhouse and Simonsen 1975) among prehistoric human populations. Butler (1972) emphasized that in an unworn state the lingual cusps of maxillary molars are highest, whereas the buccal cusps are highest in unworn mandibular molars. The higher cusps are usually the first to experience wear through tooth-to-tooth contact in normal mastication. Thus, as tooth wear increases with age the lower molars exhibit worn buccal cusps, while lingual wear is usually observed in the upper molars (Butler 1972). B. Holly Smith (1983, 1986) observed a similar phenomenon, with respect to the angle of the occlusal plane, in her samples of prehistoric human dentitions and in chimpanzees. Butler (1972) also emphasized that lateral excursions of the mandible during chewing, as well as successive differences in upper and

lower arch widths at each tooth in the posterior arcade, cause greater wear on these cusps and thus are major factors in producing the helicoidal curve. In a review article, Tobias (1980) states his belief that differences in arch width, especially great at the third molars where the mandibular arch is widest, is the simplest and most widely accepted cause for the helicoidal curve in hominids since the appearance of H. habilis. However, Osborn (1982) and B.H. Smith (1986) suggest that lingual axial tilt of the lower molars (increasingly severe for M_2 and M_3), and not arch width, is the principle contributing factor to the helicoidal wear plane. For example, B.H. Smith (1986) observed that lower molar teeth of chimpanzees, and prehistoric agriculturalists and hunter-gatherers possess lingually oriented crowns that are gradually worn on the buccal half. Smith also found that one-half of her large sample possessed equal maxillary and mandibular arch widths at M_3, while the other 50 percent possessed greater mandibular arch widths at M_3. She feels that the resulting helicoidal plane is due primarily to "differential axial implantation combined with serial eruption and wear of M1 to M3" (B.H. Smith 1986:27). Osborn (1982) noted that the Monson curve, the plane of occlusion created by molars with lingual axial tilt and very little wear, is quickly converted into a helicoidal occlusal plane by attrition caused by an abrasive diet., in conjunction with a large difference in eruption time between the first and third molars.

The presence of the helicoidal plane has been documented in many different prehistoric populations, with contrasting diets and culture-specific methods of food preparation. Kieser and colleagues (1985) present evidence of dental wear among preliterate Lengua Indians from the Chaco area of Paraguay, lending support to Osborn's theory of helicoid development because attrition in their sample enhanced the molar occlusal plane. Hall (1976) and Hall and German (1975) note that several populations of Northwest Indians possess a helicoidal pattern of occlusal wear. In addition, several other widely distributed prehistoric populations have been shown to possess varying degrees of

helicoidal plane development (Roydhouse and Simonsen 1975). McKee and Molnar (1988) found a helicoidal-like pattern in an Australian aboriginal sample, in which greater wear of the lingual cusps was observed for M_2. B.H. Smith (1983, 1986) found the helicoidal wear plane to be nearly universal in the large sample of prehistoric (agriculturalist and hunter-gatherer) human populations she studied. However, the five agriculturalist groups exhibited a higher expression of the helicoidal plane than the five hunter-gatherer groups in her sample. This may be associated with the more oblique wear planes on molar occlusal surfaces of agriculturalists (B.H. Smith 1983).

Investigators have used the presence of a helicoidal wear plane to investigate inter-species taxonomic differences, as well as relationships between different populations of the same species. For example, Tobias (1980) noted that both his and Wallace's study (Wallace 1972, after Tobias 1980) of South and East African australopithecine cheek teeth showed that the helicoidal curve was not present, although differential planes of wear existed uniformly between the maxillary and mandibular dentitions, much as in Homo. In contrast, a helicoidal wear plane was observed in Homo habilis cheek teeth (Tobias 1980). However, Osborn (1982) explored the possibility of using the helicoidal wear plane as a taxonomic tool for determining the phylogenetic relationship between Australopithecus and Homo. He concluded that the helicoidal plane has very little utility as a taxonomic indicator, based on its presence in both gracile and robust australopithecines, extant anthropoids, and modern humans from India. Osborn (1982) neglected to discuss the difference in results between his and Tobias' analysis of australopithecine material. Tobias, has greater familiarity with the original South and East African australopithecine fossils, but a cautionary note should be sounded because of the lack of opposing dental arches in some of the isolated dentitions analyzed by Tobias (1980).

Hall (1976) also emphasized that the anatomical structures of the jaws and dentition (i.e., the functional complex), as well as the helicoidal pattern itself, have likely been

selected for during the process of human evolution. She feels that such a situation would have arisen early in the evolutionary history of hominids, because of the requirement for production of occlusal surfaces that possess efficient cutting edges as well as a large surface area for mastication of food, despite the loss of occlusal enamel due to attrition. It would seem that the universality of the helicoidal wear plane among prehistoric humans, and even some living human groups has influenced most recent investigators to pay little attention to its presence in human populations. Nevertheless, its presence should be acknowledged, especially when research questions involve intra-populational variation in occlusal wear plane angles of posterior teeth. The degree of expression for the helicoidal plane may represent a significant biocultural feature of human populations, the study of which may contribute to furthering our knowledge of human biological variation.

Dental Microwear

Introduction

In this section, I use an historical approach to review microwear studies. Overlying this approach is an effort to divide the studies into two categories. First, microwear studies are examined by the types of specimens or subjects used in the analysis (e.g., fossil mammals, extant primates, prehistoric humans). Secondly, these studies are categorized by the methods used: either light microscopy or scanning electron microscopy; and whether the study is qualitative or quantitative. Many of the wide variety of studies are not easily categorized simply by their applications, because of overlapping or different fields of interest. For example, of two studies using related fossil taxa, one may emphasize a taxonomic approach while the interest of the other study may be the reconstruction of paleodiets. However, my approach is simply one way of categorizing the microwear literature (see also Bullington 1988; Gordon 1980; Kelley 1986; Maas 1988; Teaford 1988a, 1991; Walker and Teaford 1989).

Following is a detailed review of the literature pertaining to the interest in and development of analytical methods in dental microwear. Also reviewed are dental microwear studies of fossil and extant human and non-human primates, and other mammals. This discussion is subdivided into five topical sections: (1) historical interest in dental microwear, (2) masticatory biomechanics and facet production, (3) microwear analyses focused on fossil and extant mammals, (4) dental microwear of fossil and extant Hominoidea, and (5) qualitative and quantitative microwear of prehistoric human populations.

Historical Interest in Dental Microwear

Microscopic dental wear features have long been recognized as normal, but distinctive characteristics of hominids, nonhuman primates, and other animals (e.g., Brothwell 1963; Butler 1952; Dahlberg 1960b; Gingerich 1973; Pedersen and Scott 1951; Robinson 1954, 1972; Shkurkin et al. 1975). Pedersen and Scott (1951) may have been the earliest investigators to recognize and describe the differences in microscopic wear features (pits and scratches) on the surfaces of teeth from prehistoric and modern human populations (prehistoric Alaskan Eskimos, living West Greenland natives and American whites). They suggested possible developmental and functional causes for the differences observed between the groups.

Butler (1952) noted the presence of wear striae on the deciduous molars of Perissodactyla, and believed that their orientation on occlusal surfaces could be used to infer jaw movements among fossil mammals, thus contributing to taxonomic separation in different lineages. Dalhberg (1960b) also observed, at low magnification, microwear of various types which he attributed to specific kinds of abrasive material. In addition, he argued that the microscopic scratches were oriented in the direction of the occluding motion.

Numerous distinct buccolingual scratches were observed by Robinson (1954) on molar teeth of gracile and robust australopithecines. The anterior and posterior teeth of Swartkrans specimens also exhibited enamel chipping. From this microwear pattern and other evidence, such as large tooth size and rapid rate of tooth wear, Robinson argued for a predominantly vegetal diet for Paranthropus. He also noted that extraneous grit on roots and bulbs could have caused the enamel chipping.

In general, all earlier studies as well as some recent ones (e.g., Borgognini et al., 1989; Fine and Craig, 1981; Formicola and Repetto, 1989; Puech, 1979; Puech et al., 1983b; Rensberger 1978) have made use of optical microscopy at relatively low powers of resolution. The optical microscope has been relied upon primarily because of its convenience, low cost, and ease of use with minimal training. In the transmitted light mode, the light microscope can be used for examination of translucent materials (e.g., varnish impressions of tooth surfaces), as well as whole teeth, negative impressions, or positive replicas. Generally, the use of light microscopy requires very little specimen preparation, other than cleaning.

As discussed in Chapter I, the development of the scanning electron microscope, and the availability of high resolution replicating materials and casting techniques, contributed to an interest in dental microwear analyses (Teaford 1988a). The work of Teaford and Walker (1984) contributed to the development of a systematic dental microwear research protocol. Recent advances have also been made in automating microwear data collection and image analysis (Grine and Kay 1988; Kay 1987; Walker et al. 1987). Potential methodological problems inherent to these automated techniques were addressed by Walker and Teaford (1989:186) and Teaford (1991:345). According to Walker and Teaford (1989), dental microwear may not simply represent the product of what or how an individual ate shortly before death, Grine's (1986) "Last Supper" phenomenon, but actually be a record of diet and/or food preparation that occurred one to

two months prior to death. Such a short-term record is also an advantage over other methods, such as trace element analysis, which only report the sum of a lifetime's worth of eating.

According to Teaford (1991), all early quantitative dental microwear studies should be considered primarily as a set of feasibility studies, because of the limited dietary data for museum specimens, especially for non-human primates. Coarse dietary categories such as hard-object feeders, intermediate feeders, or folivores may simply mask more subtle nuances of primate diet and feeding behavior. As more specific dietary information is gathered from field observations of primates, it will be possible to correlate dental microwear with seasonal changes in diet and with the physical properties of food items (Teaford 1991). More detailed treatments of dental microwear studies follow in subsequent sections of this chapter. However, to better understand these reviews I briefly examine the biomechanics of occlusion and mastication.

Masticatory Biomechanics and Facet Production

Introduction

This section places the body of dental microwear literature in perspective with more traditional analyses focusing on the biomechanics of occlusion and mastication. Briefly reviewed here are some of the major studies of masticatory biomechanics in extant and fossil marsupials, primates, and other mammals. Because molar wear facets are of methodological importance in my research, I also briefly review some of the principle studies on the production, morphology, and terminology of occlusal wear facets.

Masticatory Biomechanics

Paleontologists and anthropologists have long been interested in the mechanics of mastication and occlusal events of fossil and extant mammals and marsupials (Beyron

1964; Butler 1952a, 1952b, 1972, 1973; Byrd et al. 1978; Crompton and Hiiemae 1969, 1970; Every 1970; Gibbs et al. 1980; Gingerich 1972, 1973; Greaves 1973; Hiiemae 1967, 1978; 1984; Hiiemae and Crompton 1971, 1985; Hiiemae and Kay 1972, 1973; Hylander et al. 1987; Kay and Hiiemae 1974; Kay 1977; Lucas and Luke 1984; Lucas et al. 1986; Mills 1955; 1963, 1967, 1973; Rensberger 1973, 1982, 1986). Early workers (e.g., Butler 1952a, 1952b; Mills 1955) used the shape and location of occlusal wear facets and the orientation of wear striations observed at low power with a binocular microscope as indicators of relative jaw movement in fossil mammals and extant primates. Later workers (Butler 1973; Crompton and Hiiemae 1970; Hiiemae 1973; Hiiemae and Kay 1972; Greaves 1973; Kay 1977; Kay and Hiiemae 1974; and Mills 1967, 1978) emphasized the use of occlusal wear facets as indicators of masticatory biomechanics in marsupials, primates and other mammals. Kay's and Hiiemae's (1974) investigation of tooth use and jaw movement in recent and fossil primates provided information on taxonomic distinctions and phylogenetic relationships. However, they stated that only the orientation of scratches, and not the direction of tooth movement, can be inferred from striations on tooth wear facets (but see Hiiemae and Kay 1972). Other investigators (e.g., Hiiemae and Crompton 1971; Hylander et al. 1987) have produced detailed functional analyses of macaque masticatory biomechanics through the use of synchronous EMG, cineflourography and strain gauge recording.

Hiiemae (1978) reviewed the plethora of terms, from simple to complex, devised to describe the masticatory cycle. The simplistic approach often involved a view of the chewing cycle as a single transitional event with no intervening phases (Atkinson and Shepherd 1961, after Hiiemae 1978). Other investigators have refined their descriptions of the masticatory cycle and associated components to include two phases or strokes (i.e., buccal and lingual phases) occurring between tooth-food-tooth contact and loss of intercuspation (e.g., Beyron 1964, Mills 1955). However, Hiiemae (1967) and Hiiemae

and Kay (1973) subsumed these two events under a single power stroke, which was preceded by a preparatory stroke and succeeded by a recovery stroke. The entire chewing cycle is usually considered to take place beginning and ending with maximum gape of the jaw (Hiiemae 1978; Hiiemae and Crompton 1985). The paper by Hiiemae and Crompton (1985) provides the best review of muscles and jaw movements in chewing, to date.

Hiiemae (1978, 1984) emphasized that a longstanding misconception in the dental literature considers the maximum forces of mastication to coincide with the point at which the teeth reach or approximate centric occlusion. However, Hylander and others (Hylander et al. 1987) have shown that the force exerted by the elevator muscles of the mandible is essentially neutral at the intercuspal position ('centric occlusion'), while peaking early in the power stroke. Consequently, trituition of food is probably not a significant result of centric occlusion.

Gibbs and colleagues (1980) analyzed the masticatory biomechanics of 18 adult subjects during the chewing of hard and soft foods. They recorded the movements of the protoconid of the first mandibular molar and of both condylar hinge axis reference points during all phases of the chewing stroke and for both working and balancing sides of the jaw. The working (active) side tooth is the one that is compressing a bolus of food between opposing occlusal surfaces. During the final phase of closure, the working side lower molar moved medially (lingualward), anteriorly and superiorly as the intercuspal position (IP) was reached. However, the balancing side molar only moved laterally and superiorly during this same chewing stroke. These masticatory motions are basically identical to those described by Kay and colleagues for the Phase I and II strokes of the masticatory cycle in marsupials, rodents and other mammals. Hiiemae and Kay (1973) cautioned however that much individual variation in humans occurs for the form and direction of jaw movement through a masticatory cycle, as a result of cultural conventions, malocclusion, and other factors.

Rensberger (1973) emphasized that repeated contact or near contact between opposing enamel surfaces during occlusion will produce the flattest wear facets. He further contended that when a tooth surface is in contact with food the wear is inversely proportional to the hardness of the tooth material, and directly proportional to the abrasiveness of the food items, contaminants, and shear stress.

Facet Production

Mills (1955) was the first investigator to describe a two-phase mandibular movement that occurred during the normal masticatory cycle of human and non-human primates. From macro- and microscopic examination of a museum collection of gorilla skulls, Mills observed two distinct sets of scratches and wear facets on the mandibular and maxillary molars. Based on this evidence, he hypothesized that an initial buccal phase of mandibular movement takes place during normal mastication, followed by a lingual phase. The lingual phase involves rotation of the mandible about the opposite (contralateral) condyle, resulting in the buccal cusps of mandibular molars sliding downward against the buccal face of the lingual cusps of the maxillary molars. The buccal phase involves rotation of the mandible about the condyle on the same side on which occlusion takes place (the ipsilateral condyle). Such a motion results in the buccal face of the buccal cusps of mandibular molars sliding upward against the lingual face of the maxillary molar buccal cusps. Essentially, the chewing pattern consists of alternate rotation of the mandible about the two condyles, with the two phases occurring "simultaneously on opposite sides of the mouth, producing a balancing occlusion" (Mills 1955:52). Mills (1955, 1963, 1967) labeled the wear facets according to the particular phase of the chewing stroke during wich they were produced (i.e., either buccal or lingual).

Buccal (shearing) facets are also described as Phase I facets (Kay and Hiiemae 1974), because they are produced through Phase I movement of the mandible during the

masticatory cycle (this is the buccal phase described by Mills 1955). During mastication of a bolus of food, the Phase I or shearing movement (the initial direction of motion) is produced as the mandibular molar teeth approach centric occlusion and shear against the maxillary molar teeth. Generally, occlusal contact of a lower molar occurs between the upper molar of the same number, and the posterior part of the immediately preceding upper tooth (e.g., Mills 1955, 1978; Kay and Hiiemae 1974). According to Mills (1978:347), the specific result of Phase I movement is such that " the protoconid of the lower molar shears across the posterior part of the buccal surface of the hypocone of the adjacent upper tooth, duplicating the action of the hypoconid" which primarily shears across the protocone of the upper molar of the same number.

In the absence of a food bolus, the termination of Phase I occurs at centric occlusion (Hiiemae 1978). However, whether all jaw movement ceases between Phase I and Phase II is debateable (cf., Kay and Hiiemae 1974; Hiiemae 1978). As the cusps on the molar teeth are gradually worn down through this process, Phase I wear facets are formed on the buccal-facing slopes of mandibular molar cusps, and on lingual-facing slopes of maxillary molar cusps. Moderately worn lower molars, such as those used in my study, possess shearing facets on the buccal-occlusal margin. The plane of a shearing facet can be oriented at various angles from the occlusal plane, but it generally faces in a buccal direction. Older people with severely worn teeth have been reported (Beyron 1964:65) to experience less vertical, and possibly more horizontal, occlusal contact between upper and lower molars during "lateral gliding" than with the unworn high cusped molars of younger individuals. Very little work has been done on the functional implications of tooth wear. Data for koalas (Lanyon and Sanson 1986) indicated that as a cheek tooth wears, the ratio of small-to-large particle sizes of gut contents remains relatively constant because of an increase in the number of cutting edges, among other factors. However, with increased wear the "occlusal efficiency" decreases, resulting in an increase in size and proportion of

food particles in the stomach. Teaford (1983b) showed that wear-related changes occurred in the slope angles of cusps on mandibular molars of Old World monkeys. He suggested that interspecific differences in the angular changes of cusp slopes, as a result of wear, have functional (i.e., dietary) significance. For modern humans, chewing efficiency for individuals who have retained their permanent teeth is probably not affected much by wear, especially with diets of relatively soft cooked foods. However, prehistoric humans with primitive food processing technologies and coarse diets may have experienced decreased chewing efficiency associated with severely worn teeth, although increased lateral excursion of worn molars (Beyron 1964) may have acted as a compensatory factor.

Phase II (crushing/grinding, lingual) facets are produced during the Phase II stroke (Hiiemae and Kay 1973) of the masticatory cycle (the lingual phase described by Mills 1955). Crushing of the food bolus is the predominant action that occurs during this part of the chewing cycle in humans and the higher primates (Hiiemae 1978). Also, Hiiemae (1984:268) believes that Phase II movement may play a significant role " in facilitating the action of the tongue in collecting adequately triturated food for transport and deglutition." During Phase II, the mandible is moving downward and mesially from the maxilla after having reached centric occlusion (Hiiemae 1978). Subsequent to this action, one or more Phase II facets are produced on the lingual surfaces of the mandibular molar buccal cusps and on the buccal surfaces of maxillary molar lingual cusps. These facets are inclined at variable angles to the occlusal plane, and their surfaces may be convex, concave or planar in shape. Also, the facet surface generally faces in a lingual direction. Although the study by Hylander et al. (1987) showed that occlusal forces are minimal at and immediately after centric occlusion, their data indicated that Phase II facets are actually formed during Phase I (buccal phase) occlusal movements when food is crushed between the Phase II (lingual phase) facets. Striations on Phase II facets are produced under relatively low occlusal

forces as a result of the relaxation of the adductor muscles of the jaw (Hylander et al. 1987).

To conform with convention (e.g., Kay 1977; Kay and Hiiemae 1974; Rensberger 1978), I use the terms Phase I and II to refer to the shearing and crushing/grinding facets, respectively. No standardized facet nomenclature or numbering system exists for humans, except for that of Maier and Schneck (1981, 1982) and Maier (1984), based partly on papers of Crompton (1971) and Kay (1977). The work on facet 'mapping' by Mills (1978) also contributed to this endeavor. However, such a system has a long history of development for fossil and modern non-human primates and other mammals (see Kay 1977 for a review). I adapted a numbering system for facets on the protoconid (cusp 1) and the hypoconid (cusp 3) of mandibular molars from Kay (1977) and Maier and Schneck (1981, 1982). This systematic facet nomenclature is described in detail in Chapter IV.

Postmortem wear on tooth surfaces is a problem that can potentially hinder microwear analysis, but several researchers (e.g., Grine 1977, 1986; Teaford 1988b) have noted that postmortem wear produces distinctive patterns that are not difficult to recognize. For example, areas of the tooth crown not normally subjected to occlusal action during the masticatory cycle, such as interproximal facets, can be examined to characterize the microscopic pattern on these enamel surfaces. If patterns of wear match those on questionable occlusal surfaces (e.g., wear facets), than the entire tooth crown had probably been subjected to postmortem wear or diagenetic processes. In such an event, the questionable tooth is usually eliminated from the microwear sample (Teaford 1988b).

Fossil and Extant Mammal Microwear

Several studies of fossil and extant non-primate mammals, such as sheep, deer, rodents, and carnivores have been undertaken (e.g., Baker et al. 1959; Covert and Kay 1981; Kay and Covert 1983; Rensberger 1973, 1978; Robson and Young 1990; Solounias et al. 1988; Taylor and Hannam 1987; Teaford and Walker 1982, 1983; Teaford and Byrd 1989; Van Valkenburgh et al. 1990; Walker et al. 1978; Wells et al. 1982; Young and Marty 1986; Young and Robson 1987; Young et al. 1987, 1990). Many of these microwear studies involved the qualitative analysis of the orientation or morphology of microscopic striations (striae) on the occlusal surfaces of teeth, in order to infer the direction of jaw movements during masticatory behavior. Other studies involved the qualitative determination of microscopic wear features to infer the paleodiet of fossil mammals or to explicate the selection of food items by extant mammals. These studies are being reviewed here, because of their historic importance in the development of dental microwear analysis and/or because of the contributions made toward the refinement of methodologies used for microwear analysis.

Rensberger (1978) was one of the early proponents of the systematic study of dental microwear for inferring dietary and taxonomic differences in fossil mammals. In this study, Rensberger analyzed qualitatively the dental microwear on the cheek teeth of several extant rodent taxa with differing herbivorous diets and tooth morphologies. His analysis utilized scanning electron microscopy at very high magnifications (up to 15,000 diameters). The extremely detailed descriptions of microwear features and wear morphology (e.g. facet shape) indicated that the six genera of rodents could be distinguished by distinctive types of wear patterns, which differed from each other in the "relative contributions of the wear components" (Rensberger 1978:430). One interesting observation was that hypsodont (high crowned) rodent teeth exhibited primarily polish, whereas the wear in the brachyodont teeth was combined with both polish and detrital

abrasion. From this evidence, Rensberger argues for greater consumption of vegetal foods with lower nutrient availability, and therefore more chewing strokes or high occlusal pressures, among hypsodont rodents. This argument is contrary to the commonly accepted belief that these rodents would tend to consume highly abrasive food items or ones contaminated with large quantities of inorganic grit. Rensberger (1978) provided one of the first detailed morphological characterizations of dental microwear features: facets, convex wear, polish, striations, furrows, fissures, flaked pits, and pebbly texture. Facets are defined as small flat enamel surfaces or "rotational surfaces" that are unidirectionally flattened, both of which are produced by contact between opposing occlusal surfaces. Polish, defined as a lack of texture, was observed on rodent cheek teeth at even very high magnifications. This would imply that in some taxa polished enamel does not change in observable surface characterstics with the levels of magnification used for examination. According to Rensberger (1978:426), striations are a set of "randomly spaced grooves of varying diameter and length" scored into the enamel by small inorganic particles (e.g., detrital rock in the soil) that are harder than enamel itself.

A pioneering dental microwear study by Walker and colleagues (1978) investigated seasonal changes in diet for two sympatric species of hyrax, Procavia johnstoni and Heterohyrax brucei, indigenous to Tanzania. The latter species is predominantly a browser of bushes and trees during both wet and dry seasons. However, P. johnstoni eats primarily grasses in the wet season, while browsing during the dry season. Scanning electron microscope examination of the occlusal surfaces of maxillary molar teeth from these two species revealed significant seasonal differences in microwear patterns. During browsing episodes, the teeth of P. johnstoni exhibited extremely fine polishing, similar to that in the browsing H. brucei. However, the former species exhibited numerous fine scratches concomitant with grazing during the wet season (Walker et al. 1978). The authors attributed this seasonal difference in microwear to the much higher concentrations

of opal phytoliths contained in grasses than in many dicotyledonous plants. Evidence exists for the abrasiveness of such phytoliths to tooth enamel. For example, severe rates of tooth wear among New Zealand sheep was attributed to opal phytoliths found in their feces (Baker et al. 1959). According to these authors, intercellular plant opal contained in the leaves of mono- and dicotyledonous plants (Piperno 1988) has a hardness slightly greater than enamel, and is capable of scoring and abrading enamel.

In a series of articles by Young, Robson, and colleagues (Young and Marty 1986; Young and Robson 1987; Robson and Young 1990; Young et al. 1987, 1990), quantitative dental microwear analyses were used to compare occlusal movements and/or diets of extant and extinct Australian marsupials. One of the more interesting results of their investigations was the finding that the types and densities of microwear features varied with location on individual occlusal wear facets. For example, a higher density of scratches was observed at the leading edge, while a higher density of large pits was observed at the trailing edge of the facet on molars of Thylacinus, in association with the direction of the occlusal stroke (Robson and Young 1990). However, intrafacet microwear variation may be a special case for the large and steeply inclined wear facets characteristic of carnassial teeth in fossil and extant carnivores. Apparently, carnivores possess two separate occlusal functions (i.e., Phase I and II) on the same facet, while omnivores have the same two occlusal functions but on different facets. Nevertheless, intrafacet variation for microwear is probably inherent to some degree for any tooth type and any mammal. For this and other reasons, care was taken during my own research to examine large portions of a facet surface and to sample an area that was representative of the entire facet (see Chapter IV for further discussion).

In a qualitative microwear study of the maxillary carnassial teeth of several species of African viverrids, Taylor and Hannam (1986) provided detailed descriptions of the microwear patterns observed with SEM. Although the authors did not reveal the

magnification used in the microscopic analysis, scales provided in the figures of the micrographs indicate that a moderate magnification (approximately 250x) was used. Distinctive patterns of microwear features, such as the orientation of microscopic grooves and scratches, were shown to be characteristic of specific viverrid taxa. However, Taylor and Hannam conceded that they were unable to determine specific causes for these microwear patterns, because of the multiplicity of variables involved in microwear production.

An empirical study by Covert and Kay (1981) produced controversy (Gordon and Walker 1983; Kay and Covert 1983) concerning the ability of microwear analyses to determine the causes of specific microscopic features found on the occlusal surfaces of teeth of fossil primates and hominids. As part of their semi-blind study, Covert and Kay (1981) fed a group of opossums different diets for 90 days, after which SEM analysis (350x) of wear facet surfaces was accomplished. The base diet of canned catfood, presumed to be free of abrasives or grit, was enriched with additions of plant fiber, chitin, or pumice grit as experimental simulations of herbivorous, insectivorous, or gritty diets, respectively. Based on the observation of several microwear parameters, it was found that the animals fed chitin showed relatively smooth microwear with few scratches, as did those fed fiber. However, the pumice-fed opossums exhibited a relatively rough microwear pattern with few pits but many parallel striations. Covert and Kay concluded that microwear may not be able to distinguish between animals with different diets, and also that naturally occurring grit produced microwear like that from opal phytoliths contained in grasses. The authors further suggested that microwear of insectivorous primates would be very difficult to distinguish from that of some herbivourous primates.

However, Gordon and Walker (1983) asserted that these conclusions were inaccurate, because of flawed design and execution of the research by the investigators. One of the problems noted by Gordon and Walker (1983) was that the animals were

probably ingesting the soft catfood with a minimal amount of mastication involved, compared to wild animals masticating a natural diet. Therefore, the abrasive additives would have either not come in contact with occlusal surfaces or for such a brief time as to not produce any wear features. However, Kay and Covert (1983) countered that the opossums experienced rapid wear of some cusps over the 3-month experimental period, including the control animals fed standard catfood. However, this kind of wear could have actually been produced by tooth-tooth contact, as noted by Teaford and Runestad (1992). A second point of criticism leveled by Gordon and Walker (1983) was that differences in masticatory forces and motion must be taken into account when comparing microwear differences between different animals, such as between opossums and hyraxes. An even more serious problem noted by Gordon and Walker concerns the lack of dietary control, because Covert and Kay apparently did not take dental impressions prior to initiating the feeding experiments.

Nevertheless, Kay (1984) and Kay and Covert (1984) have stated that dental microwear studies should not be used for dietary interpretations involving fossil primate taxa, with the exception of discriminating species that browze on tree leaves from those that graze on silica-rich grass leaves and/or forage on high-grit roots and tubers. In other words, microwear data should only be used to distinguish fossil taxa possessing widely divergent diets, at least with our present state of knowledge. Walker and Teaford (1989) emphasized that the controversy elicited by these studies brought attention to legitimate concerns about artifacts, sampling errors, and the lack of knowledge of the diets of modern and extinct species of primates. However, Walker and Teaford (1989:178) make the very valid point that the predictive ability of empirical microwear studies may be far more important, and possible, than their ability or inability to determine cause and effect.

SEM analysis and comparisons of the molar microwear of still-born and wild-trapped and laboratory guinea pigs (Teaford and Walker 1982, 1983) revealed that the still-

born animals lacked striations on their molars, in contrast to the heavily scratched molars of the adult individuals. Apparently, guinea pigs wear their recently erupted molars in utero through tooth-tooth contact, which produces enamel chipping without the microscopic striations characteristic of the tooth-food-tooth wear in adult individuals. Experimental research on the guinea pig was undertaken by Teaford and Byrd (1989) to examine the relationship between dental microwear patterns and jaw movement. Through experimentally-induced paralysis in the left side of the jaw of an experimental sample of animals and comparison with a control group, the investigators were able to show that substantial changes in microwear patterns (scratch orientations) were produced on the delimited-side lower first molar teeth compared to molars on the normally-functioning side. For example, mean scratch orientations and coefficients of variation were significantly different between right and left sides of the experimental animals, and significant differences in the variability of scratch orientation were found between experimental and control animals. Significant differences were not found for left and right side teeth of control animals. However, the authors cautioned that the unique dentognathic morphology of the guinea pig may have produced more dramatic wear changes than in other mammal species. Despite the limitations of their study, Teaford and Byrd (1989) suggested that dental microwear analysis could prove useful in clinical studies (e.g., Morel et al. 1991), for monitoring treatment effectiveness in orthodontic procedures.

Several recent microwear studies provided very detailed quantitative analyses of the microwear features on the dentitions of extant and extinct ruminants (Solounias et al. 1988; Solounias and Moelleken 1992a, 1992b; Solounias and Hayek 1993) and large carnivores (Van Valkenburgh et al. 1990). Solounias and colleagues (1988) used SEM to analyze the upper second molars of wild-shot adults of three extant Kenyan ruminants (Giraffa camelopardalis, Gazella granti, Connochaetes taurinus) with different dietary adaptations, and a Miocene giraffid (Samotherium boissieri) from Samos. Twenty-four measurements

were collected from high magnification (500x) micrographs of each molar specimen. Statistical anlyses of interspecific comparisons revealed no significant differences in feature widths between the four species, but significantly fewer microwear features for the giraffe (a browser) than any of the other species. Grazing species generally exhibited a large number of features, primarily scratches. A somewhat surprising result was the small amount of variation in the microwear patterns for Grant's gazelle (an intermediate feeder) compared to that of C. taurinus (an habitual grazer), which the authors suggest was due to the obliteration of the effects of periodic browsing by the short term but destructive effects of occasional grazing (due to the abrasive nature of opaline phytoliths). Although this could be an artifact of the small sample sizes in the study, such a result also suggests that seasonal dietary changes should be taken into account when comparing wear patterns of closely related species. Finally, the extinct giraffid exhibited proportionally more scratches than any of the extant species, but the scratch density was also closer to that of the grazer C. taurinus, indicating that this particular Miocene giraffid species had a grazing dietary adaptation.

Van Valkenburgh and colleagues (1990) studied interspecific comparisons of microwear patterns, recorded with SEM at a moderate magnification (250x), on the lower first molar (carnassial) of the extinct sabretooth cat (Smilodon fatalis) and eight extant species of large carnivores (a mustelid, felids, canids, and hyaenids). The authors noted that qualitative analysis was unsatisfactory in distinguishing interspecies differences in wear pattern, primarily because of large intraspecific variations. The results of their quantitative analyses revealed a continuum of microwear patterns associated with the range of diets of the different species. The extremes of this continuum were occupied by hyaenas (habitual bone crushers) on one end, whose carnassials exhibited relatively few features longer than 30μm and a high density of pits, whereas the cheetah molars exhibited predominantly narrow scratches and relatively few pits. The authors associate these

differences with the amount of bone crushed and consumed by the two carnivores, with hyaenas consuming relatively large amounts of bone and cheetahs relatively little. The wolf, wild dog, wolverine, and leopard, all of which possess intermediate dietary adaptations, exhibited pit densities and feature shapes that were also intermediate in microwear pattern and differed little from each other. Also, the modern carnivore scratch orientations were surprisingly variable, suggesting that most microwear was formed with food between teeth (i.e., not with teeth close to occlusion). The microwear pattern of the sabretooth cat was distinct from that of the other carnivores, consisting of long narrow features with very low variance in orientation and an extremely low frequency of pitting. From this evidence, Van Valkenburgh et al. (1990) infer that the sabretooth cat engaged in even less bone crushing than the cheetah, leaving much of the carcasses to scavengers.

Dental Microwear Research of Fossil and Extant Hominoidea

Fossil Hominoids and Hominids

The driving force behind many studies of dental microwear has been explicating the diet and subsistence pattern of early hominids. Often, research questions have focused ultimately upon taxonomic and phylogenetic problems. This is evident when the subjects of analysis are investigated from an historic perspective of the development of dental microwear as a field of study. Many investigators have contributed to the study of dental microwear in fossil hominoids and hominids (Covert and Kay 1981; Daegling and Grine 1987; Grine 1981, 1984, 1986, 1987; Grine and Kay 1988; Kay 1985; Kay and Grine 1988; Kelley 1986; Puech and Hervé 1988; Puech et al. 1980; Puech et al. 1983a; Puech et al. 1989; Rose et al. 1981; Ryan 1980a, 1980b; Ryan and Johanson 1989; Teaford and Walker 1984; Walker 1980, 1981, 1984).

Based on the results from an earlier study (Walker et al. 1978), and using a similar research strategy, Walker (1980, 1981) qualitatively analyzed the dental microwear of

several specimens of East African robust australopithecines. The dental microwear on molar teeth was indistinguishable from that of chimpanzees, orangutans, and mandrills. He concluded that grazing and browsing were not important aspects of robust Australopithecus feeding behavior. He also dismisses the bone crunching hypothesis of Szalay (1975) because of the uncharacteristic wear pattern found in this fossil species. Instead, Walker contends that frugivory is the most predominant dietary pattern of these hominids, which probably fed upon the small hard-shelled fruits common in Africa. Such a dietary regimen would have involved the mastication of the entire fruit, rather than the shell or stone being removed prior to ingestion. This also presumes that an arboreal niche and corresponding locomotor pattern were predominant for the robust australopithecines. Walker's hypothesis corroborates much of the skeletal evidence for an inefficient type of bipedal locomotion among the Australopithecinae, in which they were at least partially committed to arboreal life and/or feeding in the ecotone between the forest and savanna.

Rose and colleagues (1981) used SEM to analyze macro- and microscopic striations on incisors of the mandibular tooth combs of extant and extinct prosimian primates. They found a pattern of fine and vertical grooves on the lateral and medial sides of the teeth from the fossil primates similar to those on the extant prosimians, leading them to conclude that the tooth combs in both taxa were used for grooming behavior. In a brief review of australopithecine tooth wear, Kay (1985) acknowledged the microwear differences between the gracile and robust australopithecines, but was pessimistic about the ability to derive many generalizations from the available microwear data regarding australopithecine dietary differences.

The dental microwear of African hominids has been analyzed with SEM and reported in a series of articles by Grine (1977, 1981, 1984, 1986, 1987; Kay and Grine 1988; Grine and Kay 1988). Grine (1981, 1984) qualitatively analyzed the microwear on the deciduous molar teeth of one 'gracile' and three 'robust' species of australopithecine

from South Africa. Each of these species exhibited a different microwear pattern, indicating occupation of a different environment with concomitantly different diets. For example, Australopithecus africanus inhabited a wet environment in South Africa and its deciduous molars exhibited a shearing-type of microwear, consisting of polished and finely scratched Phase I facets. This is indicative of a moderately tough herbivorous diet for the 'gracile' australopithecines. The dental microwear of the 'robust' australopithecines consisted also of scratched and polished Phase I facets, but with more and coarser pitting, indicative of a diet involving crushing and grinding of a large quantity of more fibrous and/or harder food items. However, Grine admits that Australopithecus and Paranthropus could have had nearly identical diets during much of the year, but that the 'robust' individuals may have seasonally reverted to harder and more fibrous items essential to their nutritional intake. Microwear differences were also found between A. africanus and the 'robust' australopithecines in the functional complex involving the upper deciduous canine-lower deciduous first molar.

These microwear differences, as well as allometric differences for the anterior teeth, ultimately argue for a taxonomic separation for the 'robust' and 'gracile' australopithecines, in line with the early arguments of Robinson (1954, 1972) and others, and contrary to the sexual dimorphism hypotheses of Wolpoff (1971a, 1973, 1980) and Brace (1973). Grine further argues for an evolutionary relationship between the South and East African australopithecines, which associated the evolution of the australopithecine masticatory complex with environmental degradation from the 'gracile' species through the 'robust' species. He concludes that "the observed trophic changes reflect increased mastication of the relatively tougher, more fibrous and/or harder foods which would have been more plentiful in drier environments" (Grine 1981:223).

Quantitative dental microwear analyses, accomplished with SEM at moderate magnifications, were also applied by Grine (1986, 1987) and Kay and Grine (1988) to

permanent maxillary molar teeth of Australopithecus and Paranthropus, and reaffirm the earlier qualitative comparisons. The results of these studies indicated that Paranthropus occlusal surfaces differed significantly for several microwear parameters when compared to Australopithecus microwear. For example, pits are smaller and scratches narrower on either Phase I or II facets of Australopithecus molar crowns, and the pit frequencies and feature densities are significantly lower. Also, Grine (1986) suggests that the greater heterogeneity of scratch orientation on Paranthropus crowns may be due to increased eccentricity of jaw movements, and ultimately to a difference in the mechanical properties of foodstuffs ingested by Paranthropus compared to Australopithecus. Essentially, the Fourier transformation methodology used by Kay and Grine (1988; Grine and Kay 1988) mirrors the differences between the taxa based on more traditional metric microwear data. These quantitative dental microwear analyses, as well as the qualitative studies, indicated that Paranthropus was a committed hard object feeder, not just an occasional consumer of these hard food items, whereas the Australopithecus diet consisted of softer foods such as leaves and/or soft fruits. Furthermore, the availability of foods of different mechanical properties may have been associated with the xeric or mesic environments inhabited by the robust and gracile australopithecines, respectively.

Puech and colleagues (Puech et al. 1983a; Puech et al. 1989) used qualitative dental microwear analyses, accomplished primarily with optical microscopy, to study on food choices available to hominids, ultimately associating microwear types with habitats. For example, Puech et al. (1983a) emphasize that Australopithecus afarensis from Hadar and Homo habilis from Olduvai inhabited very similar lakeside environments, but they exhibit different microwear patterns. Although Phase I facets of both Hadar and Laetoli cheek teeth exhibited a similar number of coarse striae, the latter also exhibited pitting. The H. habilis cheek teeth exhibited a few fine striae on Phase I facets, and were generally smoother and more polished than any of the A. afarensis molars. The authors emphasize

that the Hadar australopithecines and Olduvai habilines resided in very similar lakeside environments, but the microwear differences suggest that culturally these two hominids were eating different diets, and therefore occupying different trophic levels. An alternative hypothesis offered by the authors suggests that the two taxa were preparing similar foods differently, such that H. habilis washed its food whereas A. afarensis did not. However, their conclusions should be accepted cautiously, because of the small sample sizes (e.g., a single Olduvai specimen), their reliance on optical microscopy, and the fact that they make no mention of the possibility of postmortem wear.

A more recent study by Puech and Hervé (1988) compared the dental microwear of Olduvai habilines with the Peninj Australopithecus boisei specimen. As in his earlier research, Puech found microwear differences between the habilines and the australopithecines. The latter species possessed incisor teeth with chipped enamel and heavily scratched posterior teeth, indicative of a tough diet of roots and tubers contaminated by grit particles. However, the Olduvai habilines exhibited eroded dentine and enamel on incisal and occlusal surfaces, similar to the erosion of tooth enamel produced by the chewing of mildly acidic foods. From this evidence, the authors conclude that "acidic water-edge vegetable eating" was practiced routinely by H. habilis.

Kelley (1986) conducted a qualitative, low-magnification SEM analysis of Miocene hominoid incisor microwear, compared with several living catarrhine and one platyrrhine species. Assuming that anterior microwear "reflects food procurement tasks and certain physical properties of dietary items," Kelley determined that several species of Sivapithecus and Proconsul consumed a "generally frugivorous-herbivorous diet" that was as diverse as that observed for the primate species (Kelley 1986:337). He found that anterior tooth microwear alone was insufficient to allow the inference of finer distinctions within these broad dietary categories, but speculated that such inferences would become more feasible with an expansion of the dental microwear data base for extant primates.

Puech et al. (1989) used scanning electron microscopy to analyze the dental microwear on maxillary canine teeth of Spanish dryopithecines. Their analysis focused on three functional domains of the canine tooth: "mesioocclusal wear with the lower canine, tip wear, and distolingual wear facet with a third lower premolar" (Puech et al. 1989:307). For example, the blunted cusp tips exhibited large pits and a pebbly texture, while buccal enamel surfaces showed numerous vertical striations. According to the authors, these types of microwear indicate mastication involving puncturing and high pressure crushing. Furthermore, the microwear was attributed to a diet that included woody vegetation and hard items, such as nuts and seeds, which the authors ultimately associate with drier and more open woodland habitats than occupied by the dryopithecines of Central Europe. Using optical microscopy, Puech (1979) and Puech et al. (1980) analyzed the buccal surfaces of molar teeth from Neanderthals and from a comparative hominid and prehistoric human sample. The principle variable in the analyses was the orientation of scratches on the buccal surface, produced by movement of the bolus of food as it was compressed by the cheeks. The orientations were recorded in the form of "star diagrams." Predominantly vertical scratches were observed on the single tooth specimen from one of the archaic H. sapiens specimens from Broken Hill, although some oblique striations were also present. Based on this evidence, the authors suggest that these middle Pleistocene hominids included meat in their diet, rather than relying entirely on vegetable food.

A qualitative SEM analysis of the buccal surfaces of anterior teeth from a sample of middle Pleistocene hominids (Bermúdez de Castro et al. 1988; Fernández-Jalvo and Bermúdez de Castro 1988) revealed numerous obliquely-oriented scratches with a range of widths. Non-hominid mammal teeth from the site (Atapuerca) exhibited dissimilar scratch patterns. Much finer scratches were found on posterior teeth than on the labial surfaces of the hominid incisors. From the size, orientation, and morphology of these scratches, compared to ones produced experimentally, the authors infer that these hominids were

using a stone tool in a sawing motion to cut pieces of meat or other material held between the incisors. Additional evidence was provided to suggest that handedness and brain lateralization existed among these hominids (Bermúdez de Castro et al. 1988).

Extant Primates from Museum Collections

Many dental microwear studies have been conducted on extant primates, using wild-trapped individuals in field research applications or specimens from museum collections (Gordon 1980, 1982, 1984a, 1984d; Hojo 1991a, 1991b, 1992; Janis 1984; Kelley 1986; Ryan 1979a, 1980, 1981; Teaford 1983, 1985 1986; Teaford and Glander 1991; Teaford and Robinson 1989; Teaford and Runestad 1992; Teaford and Walker 1984; P.L. Walker 1976; Walker and Teaford 1989; Ungar 1990, 1992a, 1992b).

An early quantitative dental microwear analysis of wild-shot specimens of Old World monkeys was undertaken by P.L. Walker (1976), in which low-magnification optical microscopy was used to examine the maxillary central incisors of several species of arboreal colobine and terrestrial cercopithecine monkeys. Walker determined the frequencies and orientations of scratches on occlusal wear facets of the incisors, and investigated the interspecific differences with chi-square analysis. Results of his analysis showed that significant differences existed between terrestrial and arboreal genera of Old World monkeys for both scratch frequency and orientation. He suggested that the significantly (and unexpectedly) higher density of scratches for arboreal monkeys could be explained by a diminished obliteration of striations associated with a lower overall rate of attrition, compared to terrestrial forms. An association was drawn between the scratch frequencies and the "habitat preference and the mechanical characteristics of food items exploited." The predominantly labiolingual orientation of scratches on the cercopithecine incisors and mesiodistal orientation of scratches on the colobine incisors was hypothesized to "reflect the direction of mandibular movement during mastication and probably also use

of the hands to pull or push food objects across the teeth" (Walker 1976:306). A study of finer distinctions in incisor microwear (Teaford 1983) concentrated on two species of langurs from Borneo, in order to determine the association between differences in underbite and diet. The distinctive microwear pattern found on the Presbytis rubicunda incisor teeth (higher proportions of labiolingually-oriented scratches) supported the dental/palatal metric data for a greater incidence of underbite compared to P. cristata. Both lines of evidence were indicative of specialized manipulative use of the incisors by P. rubicunda. The author suggested that these differences for P. rubicunda were associated with a diet containing a substantial proportion of legume seeds. The use of the incisor teeth to open the legume pods produced the distinctive microwear pattern on the anterior teeth.

Gordon's dissertation research (1980, 1982) on a small sample of chimpanzee (Pan troglodytes verus) skulls stands as a pioneering work in quantitative microwear analysis. She was interested in differentiating jaw movement between chimpanzees and fossil hominids by analyzing differences in orientation of microscopic scratches, as well as differences in scratch and pit dimensions, between upper and lower teeth and between taxa. She was also the first investigator to develop and urge the standardization of methods for microwear analysis. In this study, microwear differences were found between molars of the same arcade. Generally, a greater proportion of microscopic pits were observed on facets of second molars when compared to first molars, whereas a greater proportion of striations were exhibited by the anterior molars. Gordon considered this difference to be due to the different masticatory function of successive molar teeth. Because of its nearer proximity to the craniomandibular articulation (CMA), the biomechanical forces of mastication cause the lower second molar to have a crushing function. In contrast, the lower first molar was shown to have a shearing function, because of its greater distance from the CMA. Despite tooth position, the length of striations was found to be greatest on shearing facets and shortest on grinding surfaces. This is at least partially due to the fact

that shearing facets are inclined more than other facets and thus experience low compressive loads during chewing. These and other significant microwear differences observed between successive molar teeth and between different wear facets were inferred to be a result of variation in masticatory biomechanics rather than diet. Therefore, Gordon (1980, 1982, 1984a, 1984d, 1988a) recommended that only homologous teeth and facets be compared in quantitative microwear analyses. Other work by Gordon (1984b, 1984c, 1988a) has been devoted to the methodological and technological problems inherent to dental microwear analysis (e.g. electron beam-specimen geometry). Her work is reviewed in greater detail in Chapter IV).

A model for occlusal attrition presented by Osborn (1982) reinforces this view. In this case, Osborn (1982) noted that, in the presence of a helicoidal wear plane, the molar teeth of a single arcade function in series, one after another, during a normal power stroke. He concludes that the force of the power stroke could then be exerted "sequentially on each tooth, rather than spreading it equally between all three molars" (Osborn 1982:281).

In addition to the early quantitative work by Gordon (1980, 1982, 1984a, 1984d), Ryan also conducted a semi-quantitative and comparative microwear analysis of the anterior dentition of modern primates, prehistoric humans, and fossil hominids (Ryan 1980a, 1980b, 1981; Ryan and Johanson 1989). The three primate taxa consisted of Pan troglodytes, Gorilla gorilla, and Papio hamadryas, while the prehistoric human sample included individuals from Libben, a Late Woodland site in Ohio, and Ipiutak Eskimos from Point Hope Alaska. Also included in the sample were several Australopithecus afarensis specimens, and several Neanderthal specimens from Europe and the Near East. This is a semi-quantitative study with measurements and descriptive statistics provided for the following microwear parameters: densities (number of pits and striae) per square millimeter; mean pit diameter; scratch orientation (in degrees); and total number of microflakes per species. However, the bulk of the SEM analyses were done at low

magnification (35-50x), and composite 'maps' were assembled from the micrographs to show the entire labial and incisal surfaces of the anterior teeth.

In his analysis of non-masticatory tooth function, Ryan found distinct types of microwear for the three primate species, which he believes reflect differences in diet, manipulation of food items, and initial chewing with the anterior teeth. For example, the chimpanzee exhibited a microwear set consisting of many small pits, and mesiodistally oriented striae. Husking of hard fruits and drawing leaves laterally across the teeth are associated with these respective microwear types. The microwear set of Australopithecus afarensis incisors was most similar to that of the gorilla, in which the primary feature at low magnification was polish, while labiolingually oriented fine striae and low densities of small pits were found at high magnification (500x). Such a pattern was related to the initial ingestion of large quantities of vegetation, which probably involved plant fibers containing opal phytoliths or grit particles being pulled across the tooth surfaces. Clusters of large pits and microflaking along the labial enamel surfaces on one of the Australopithecus specimens suggested to Ryan that paramasticatory holding, clamping and pulling behaviors were practiced, as with the Eskimos. Also suggested was that the individual consumed seeds, roots, and rhizomes, because the microwear partially resembled that of Papio. However, these inferred dietary activities should be accepted with caution, since such a microwear pattern may simply represent idiosyncratic behavior.

In addition to the microwear set of early hominids, microscopic gouges were observed on the anterior teeth of prehistoric Eskimos, as well as a sample of Neanderthals (Ryan 1980a, 1980b; Ryan and Johanson 1989). Neanderthals also exhibited a similar microwear pattern on the maxillary canines. Ryan attributes this type of microwear to non-masticatory use of the anterior teeth for activities such as power-grasping and clamping (i.e. use of the teeth as a 'third hand'). However, Woodland Indian incisors exhibited large wear patches, which Ryan suggests were caused by the initial preparation of foods

contaminated with grit. The canine/premolar complex of these Woodland Indians was generally worn flat, with extensive pitting on the premolars, a pattern Ryan attributes to grinding and puncture-crushing of grit-laden food items. A similar function was suggested for the A. afarensis canine/premolar complex, although the canine apex was not worn as flat as the prehistoric Indian teeth.

A qualitative and optical microscopic analysis by Janis (1984) investigated the relationship between the 'gross' wear on molar teeth and the variation in the diet of three closely related species of colobus monkey (Colobus satanas, C. badius, C. guereza). This was a purely observational study in which molar occlusal surfaces were drawn and occlusal wear facets categorized using the terminology of Kay (1977). She noted the possibility of intrafacet differences within species, and she found small but consistent molar wear differences between the three species, which appeared to be associated with the slight dietary differences. For example, C. satanas, with a diet comprising only 40% leaves, exhibited smaller areas for buccal Phase I facets than did C. guereza, where a diet comprising about 70% leaves is common. This is significant because it indicates that intraspecies wear differences may also be observable where fine dietary differences are dependent upon regional, ecological or seasonal differences. Microwear differences related to differences in ecology or climate have been shown recently for New World monkeys (Teaford and Robinson 1989). Janis concluded that these results could be used to predict the diets and paleoecology of extant species of primates, and she used three species of Eocene adapid primates as examples of this. Her predictions are interesting but certainly not conclusive, being based primarily on estimated body weights and the association with different dietary adaptations, such as insectivory. Other problems include the non-quantitative determination of facet area, which included a non-standardized tooth orientation for the microscopic examination, as was also a problem of the study by McKee and Molnar (1988).

The first comparative and quantitative analyses of non-human primate dental microwear were accomplished by Teaford and Walker (1984). Their study stands as a landmark, because of the careful and standardized techniques these investigators developed and used, as well as the comparative nature of the sample. The authors noted the uncertainties expressed by various investigators regarding the exact causes of specific microwear features, but they emphasized that studies of extant species of primates with known diets can be used analogously to interpret the paleontological record. The primates in the sample included: three species that feed primarily on leaves, stems and flowers (Alouatta palliata, Colobus guereza and Gorilla gorilla); the chimpanzee (Pan troglodytes), which has an intermediate and more omnivorous diet of soft fruit; and three species that are hard-object feeders (Cebus apella, Cercocebus albigena and Pongo pygmaeus). A review of the methodological features of their study and detailed discussion of the analytical techniques adapted for use in this dissertation are presented in Chapter IV.

A comparison of mandibular and maxillary second molar teeth showed no signifcant differences, so Teaford and Walker (1984) inferred that either upper or lower molars could be analyzed. Results of the analyses indicated that the second molars of folivorous primates possessed many long and narrow microwear features (range of mean widths of 1-2μm), few pits, and much enamel prism relief. Conversely, the frugivorous species that specialized in feeding on hard fruits exhibited shorter and wider features (range of mean widths of 3-7μm) and much pitting on molar facets, but little prism relief. Sivapithecus indicus molars exhibited intermediate microwear features, very similar to those of the chimpanzee. While the average number of features per field was not in itself a significant feature of the interspecific comparisons, the chi-square tests showed that the interspecific distributions of pits and scratches were all significantly different from each other. Because of the wide variation in mean widths between species, the authors suggest that statistical and purely quantitative analyses may require supplementation with qualitative

and descriptive analyses of microwear features. Part of the problem may be due to the arbitrary 10:1 length-to-width ratio selected to separate scratches from pits. This was evident with the three folivorous species who showed wide variation in means but similar shapes of microwear features. Teaford and Walker cautiously concluded that the number of pits on molar occlusal surfaces of Pongo and other frugivores may be associated with their diets of hard nuts and fruits. However, they noted that the microwear similarities of Sivapithecus with the chimpanzee, which eats soft fruit and possesses moderately-thick enamel, does not seem to fit with the very thick molar enamel of the Asian hominid. Therefore, Teaford and Walker believe that dietary adaptation may not explain the thick molar enamel of Sivapithecus, as others (e.g., Kay 1981) have proposed.

Other dental microwear studies of wild-shot primates include Teaford's (1985) analysis of maxillary second molars from three species of Cebus and from two species of colobine monkeys (Teaford 1986). Replicas of the museum specimens were analyzed using SEM, and micrographs were taken of both a crushing/grinding facet (#9) and a shearing facet (#3). Quantitative measurements, such as feature widths and relative proportions of pits and scratches, were analyzed with chi-square and a multiple comparison test. The crushing/grinding facet (#9) of all species exhibited a greater density of pits and fewer scratches than the shearing facet. Similar results were also demonstrated in previous studies (Gordon 1982, 1984; Teaford and Walker 1984). Although pit widths were not significantly different between the two species of Colobus, significant interspecific differences were found for the average width of pits on molar specimens from the Cebus sample. However, it should be noted that mean values for pit width published in a later paper by Teaford (1988a: Table1) indicated smaller differences between the three Cebus species. Nevertheless, the widest pits were exhibited by C. nigrivittatus and C. apella, which have a well-documented propensity for feeding on hard fruits and other hard food items, such as snails. Hard-object feeding by this cebid species was also indicated by the

higher proportion of pits compared to that of C. capucinus, which reflected the inability to process hard food items or outright avoidance by the latter species. Teaford suggested that additional and more detailed behavioral and dietary data for the three Cebus species would lead to more definitive hypotheses about their dental function and dietary adaptations.

Recently, seasonal or ecological variation in molar microwear, and its association with diet, was investigated in wild-shot specimens of Cebus nigrivittatus (Teaford and Robinson 1989). Specimens were obtained from the Smithsonian Venezuelan Project, in which individuals were collected from "three distinct ecological life zones that are distinguished by both the amount of rainfall and its seasonality" (Teaford and Robinson 1989:391), and by the associated dietary resources which vary seasonally in response to fluctuations in rainfall. Standardized SEM micrographs were taken of crushing facet 9 on replicas of maxillary second molars from each of 62 individuals. Quantitative data, such as relative proportions of features, pit width, and scratch width, were collected and analyzed using a multiple comparison test. The intraspecies comparisons revealed only very small and non-significant differences in microwear patterns between ecological life zones, probably because significant seasonal differences in microwear patterns were found for animals sampled within certain ecological life zones. For monkeys from the dry tropical woodland site, a greater number of features, especially scratches, and fewer and smaller pits were exhibited by animals collected during the wet season than during the dry season. The authors suggested that more dramatic ecological and seasonal differences than were true for their three samples would probably be reflected in significant molar microwear differences within species.

One of the more interesting results was the uniformity in scratch widths for individuals within the sample. The authors found these results to be similar to those shown for ruminants (Solounias et al. 1988) and suggested that perhaps abrasives of relatively the same size had scratched the teeth of the different taxa. Although the problem of geographic

variability in microwear for the same species of monkey should cause some concern for interspecific taxonomic studies, it actually proves useful if one is interested in distinguishing dental microwear patterns among identical species (e.g., humans) living in populations with geographically or chronologically variable diets. As Teaford and Robinson (1989) point out, however, seasonal differences in molar microwear may be a mitigating factor when comparing the same or similar species, and add further emphasis to the need for large samples.

Based on these conclusions, several genera of Venezuelan monkeys collected during the same month from the same humid tropical forest locations were subjects of a recent dental microwear study (Teaford and Runestad 1992). The research protocol was identical to that used by Teaford and Robinson (1989). The statistical analyses included two-way analysis of variance in order to explore interactive effects of the genus, collection site, and/or season on the microwear variables. The authors noted that the large amount of variation in the samples prevented finding many significant differences. Differences in the season of collection generally produced few significant microwear differences, as might be expected at humid tropical forest sites where resource availability is relatively constant. Significant differences between genera, however, included feature densities, the proportions of small and large pits, and pit width, although the widths of scratches were generally not significantly different between the genera. For example, Pithecia and Chiropotes exhibited a high preponderance of both small and large pits, in contrast to Cebus which had low pit densities but the largest pits of any of the genera. The authors suggested that the microwear pattern of the former two genera was a result of the inclusion of both hard and soft fruits in their diets. The unusual microwear pattern in Cebus and some of the other monkeys with more variable diets was attributed to occasional inclusion of hard food items in the diet, which could produce unusually large pits given the normal diets of these animals. From these contrasting results, the authors concluded that small and

large pits were formed differently, such that large pits "might well be fractures in the enamel caused by the compression of hard objects between enamel surfaces" (Teaford and Runestad 1992:360). However, tooth-on-tooth wear may cause small pits to form along enamel prism boundaries as a result of either microscopic fracturing or adhesive wear. The authors pointed out the limitations of using museum specimens for dietary reconstruction based on dental microwear, especially because of the inability to associate microwear patterns of individual animals with their feeding behaviors (i.e., the lack of detailed dietary information precluded the separation of some interpretations from others). However, these and other important cautions were augmented with a note of hope for future dental microwear research, especially involving live animals from whom current detailed dietary information was available. Such research using live wild-trapped primates was accomplished in a recent study by Teaford and Glander (1991) (see review below).

Recently, a very comprehensive study of Sumatran anthropoids was accomplished by Ungar (1992a, 1992b), and was an extension of an earlier pilot study of New World monkeys (Ungar 1990). During a 9-month period, he collected field observations on the feeding behavior (diet and anterior tooth use) of two species of monkey (Macaca fascicularis, Presbytis thomasi) and two species of Asian ape (Pongo pymgaeus, Hylobates lar) residing in different levels of the rain forest. The anterior dental microwear was also analyzed in wild-shot museum specimens of these species from northern Sumatra. Interspecies differences in dental microwear were associated with differences observed in the wild animals for feeding height, and the method and proportion of time spent consuming a specific food item. The results of this study and their implications are discussed later in this dissertation (see Chapter VII).

Live Wild-Trapped Primates

In a recent study by Teaford and Glander (1991), a large number of mantled howler monkeys (Alouatta palliata) from Costa Rica were caught and sedated for the purpose of obtaining dental impressions. Using epoxy replicas, high magnification (500x) SEM micrographs of facet 9 on the mandibular second molars were used to identify and measure microwear features. Lower magnification (200x) micrographs were taken from baseline and follow-up replicas collected from animals caught several days later. These were used to calculate rates of wear occurring within a 7-day period. Results confirmed that high quality dental impressions could be taken from primates in the wild. In addition, these howler monkeys exhibited a greater density of microwear features, a greater proportion of pits, and wider scratches than museum specimens collected from Panama. Intraspecies microwear differences were also found when the live sample was divided by trapping location. Based on these results, the authors suggested that ecological and/or seasonal differences may be mitigating factors in the type and amount of abrasives ingested by different populations of the same primate species, as has also been shown by previous studies (Teaford and Robinson 1989). Furthermore, the wild-trapped howler monkeys revealed significant interfacet microwear differences, and also a significantly greater incidence of microwear features than for a sample of human dental patients. Also, the direction of the interfacet microwear differences for the howlers was opposite to that exhibited by the modern human sample (see later review of the paper by Teaford and Tylenda 1991).

Several studies undertaken by Hojo (1991a, 1991b, 1992) investigated the dental microwear of canine and molar teeth in wild-caught Japanese macaques (Macaca fuscata). One of these studies (Hojo 1992) consisted primarily of qualitative descriptions of the microwear and enamel structure of canine teeth. The author concluded that wild Japanese macaques are bruxists (i.e., grind their teeth) and ingest hard foods. Comparisons of

dental microwear parameters from facet 9 on mandibular second molars of Japanese macaques (Hojo 1991a) with that reported in the literature for other primate species showed similarities with hard object feeders. For example, the mean percentage of pits was nearly identical to that reported by Teaford (1985, 1986, 1988a) for Pongo pygmaeus, Cercocebus albigena and Cebus apella, species that have been reported to feed on hard fruits and other items. Also, the mean scratch width on the macaque molars was significantly greater than that reported for these same species, as well as for Colobus guereza.

Experimental Microwear Research using Primates

Teaford and Oyen (1989a, 1989b) conducted a longitudinal study of dental wear in growing vervet monkeys raised on hard versus soft diets. At regular intervals during the study, dental impressions were taken of the left mandibular first molar for the purposes of measuring the cusp height of the crown and the area of dentine exposure on the buccal cusps. The painstaking methodology developed for sedating live nonhuman primates and taking high quality dental impressions has been described elsewhere by the authors (Teaford and Oyen 1989d). The study showed that microscopic and macroscopic tooth wear were directly correlated, such that monkeys fed hard diets had greater reduction in cusp height, as well as faster dental microwear turnover, compared to monkeys raised on soft diets. Results of statistical analyses led the authors to conclude that these differences in rates of wear were due to the food consistency in the diets of the monkeys, which ultimately could be explained by the greater length of time spent chewing by the animals on the hard diet. The authors cautioned that differences in microscopic wear rates between different molar facets may indicate that the relationship between macroscopic and microscopic wear may be complicated, as well as the mechanisms by which wear occurs in diets of different consistency.

As part of their longitudinal study of tooth wear in captive vervet monkeys, Teaford and Oyen (1989c) compared the dental microwear produced during short-term feeding experiments with the microwear produced through in vitro experimentation on a small sample of baboon molar teeth. Baseline dental impressions of the left mandibular molars and two other sets of impressions taken over a four-day period were used to produce positive casts, from which SEM micrographs were taken of shearing and crushing/grinding facets. Statistical analyses of the feature count data revealed that turnover rates in the laboratory monkeys were fairly high, with obliteration of some microwear features occurring within 24 hours. From the experiments with the isolated baboon molars, it was shown that multiple features could be produced in the enamel with only a single pass of a monkey chow biscuit. This confirms Teaford's (1988a) contention that microwear features should not be considered as independent events in statistical analyses. Dental microwear turnover has certainly been discussed by other investigators. In fact, Grine (1986) referred to the phenomenon of changing dental microwear patterns within the life of an animal as the 'Last Supper' phenomenon. In other words, microwear may only reflect what a modern or fossil animal ate within weeks or days prior to its death. Teaford and Oyen (1989c) reached three major conclusions regarding dental microwear turnover. First, the rates for turnover were relatively fast for primates, but much slower for humans. Second, Phase II (crushing/grinding) facets of vervet monkeys exhibited faster turnover than Phase I (shearing) facets, whereas howler monkeys exhibited opposite turnover differences. Finally, hard, coarse food produced a more rapid rate of turnover than soft food (e.g., water-softened monkey chow). The authors concluded that some of the effects of microwear turnover could be mitigated by using large interspecies samples in comparisons of dental microwear for species with variable diets.

Dental Microwear Analyses of Prehistoric Human Groups

Experimental Research using Extracted or Dry Human Teeth

To date, few analyses of dental microwear have been done on living human subjects in an experimental setting. Teaford and Tylenda (1991) conducted a longitudinal dental microwear study of nine adult volunteers to document changes in microwear resulting from consumption of a 'normal' American diet. They noted that decreases in molar cusp height typically are not detectable macroscopically until large amounts of time (i.e., 12-18 months) have passed, because of the slow rates of wear for most human groups. SEM analysis of replicas from baseline and follow-up impressions, and comparison with experimental data from captive vervet monkeys raised on a soft diet (Teaford and Oyen 1989c), revealed that the human subjects experienced significantly slower tooth wear. However, microscopic changes (number of new pits and scratches) in the human teeth were discernible after periods as short as one week. Similar changes observed in the vervet monkeys were significantly correlated with annual changes in cusp height. Also, the direction of the interfacet microwear differences for the modern human sample was the same as that exhibited by the vervets, but opposite to that in howler monkeys (Teaford and Glander 1991). In other words, most of the volunteer subjects who ate soft prepared foods showed faster wear on crushing/grinding facets than on shearing facets, probably because such a diet would not typically require cutting or shearing action by the teeth. Teaford and Tylenda (1991) suggested that such studies could be useful in clinical dentistry for monitoring the affect of clinical procedures on age-related tooth wear (e.g., Pine 1992).

Other investigators have used extracted teeth from modern humans or archaeologically derived teeth in experimental research. For example, Maas (1988, 1989) used teeth extracted from modern humans and from several species of extant nonhuman

primates in an experimental analysis of the relationship between dental microwear and enamel microstructure. Based upon a series of shearing and compression experiments, she concluded that the size of grit particles did not significantly influence the widths of scratches on enamel surfaces, but was significantly associated with pit size. Also, scratch width is not simply explained by knowledge of the prismatic or subprismatic structure of enamel, but the width of striations produced during shearing experiments may be different for prismatic and nonprismatic enamel (Maas 1988:338-339). Maas concluded that subprismatic structure rather than the organization of enamel crystallites into prisms, is chiefly responsible for variation in scratch width, especially for small grit particle size. Finally, the area encompassed by microwear features was not found to be significantly influenced by the magnitude of compression forces used in the experiments. Walker's (1980:188-194) dental microwear study includes an excellent discussion and illustrations of ablation of dentinal tubules and enamel prisms.

Two experimental microwear studies by Ryan (1979a, 1979b) were discussed in the attrition section of this chapter. These studies involved the application of incisor teeth from prehistoric Indians and from modern human extractions to a grit-laden surface, either by hand sliding or with a mechanical device. Ryan concluded that striation morphology and orientation indicated the direction of wear. He described a characteristic scratch as one with "a broadly pitted point of contact with an extending groove that becomes narrower and which seems to correspond to the buccal phase of mastication when the mandible is drawn upward, forward and slightly medially" (Ryan 1979b:166).

However, Teaford and Walker (1983) and Gordon (1984) criticized Ryan's directional model. From their experimental dental microwear analyses of guinea pig (Cavia porcellus) teeth, as well as from theoretical issues of abrasive wear between flat surfaces, Teaford and Walker showed that scratch morphology was exactly opposite to that describd by Ryan. Scratches produced through normal wear on occlusal surfaces of teeth exhibited

gradual widening from the point of contact, terminating in a pit at the end of motion. Many examples of this kind of scratch production were found during my research, contrary to that reported by Ryan (1979a, 1979b). For example, a buccolingually oriented scratch on a Phase I facet typically possessed a pit at the buccal end, or at the cervical end in the case of steeply tilted facet surfaces. In many cases, it was not possible to discern the direction in which the scratch tapered, because most scratches were truncated by the field margins at the high magnification (500x) used in my research (see Chapter V). Teaford and Walker (1983) also emphasized that the biomechanics of scratch production are extremely complex and require in vivo experimentation to be fully comprehended.

Peters (1982) used an experimental approach to test the two predominant dietary hypotheses for the 'robust' australopithecines. Epoxy replicas (controls) were cast from freshly extracted third molars from dental patients prior to conducting force-deformation experiments on the extracted teeth. The experiments involved force loading test items (e.g., steer bone, mongongo nuts, carob beans, onion bulbs) onto the occlusal surface of tooth specimens, until the fracture point of either or both materials was reached. Under SEM examination, microwear from the mongongo nut experiment consisted of very few parallel, broadly subparallel and extremely narrow scratches on cusp tips. Peters attributed these to sand grains adhering to the surfaces of the nuts but suggested that seed-coats themselves were unable to produce striations greater than or equal to 0.1μm. Also, puncture-crushing of soft bulbs contaminated with grit particles produced few scratches. Microscopic cracks in the surface enamel apeared to be the predominant feature resulting from these experiments. From these results, the author suggested that it may be difficult to directly associate microscopic scratches with a particular type of food, food processing, or environmental cause.

While Peters' (1982) research is admirable for its technical sophistication, several fundamental problems exist. One which the author acknowledges is that the speed of

puncture-crushing in the experiments was much slower than in normal mastication, in which a lower force is exerted with greater speed. For example, the force obtained with steer bone was two to three times the highest molar bite forces exerted by Eskimos. The complex mechanics of mastication were not accurately modelled by the force loading protocol, precluding a test for normal movements of a food bolus against a tooth during mastication. Also, because of interspecific variation in enamel decussation patterns, it may be inappropriate to use modern human molar teeth to infer the microwear patterns for the 'robust' australopithecines.

Several experimental dental microwear studies have been carried out by Puech and his colleagues (Puech et al. 1981, 1986, 1988). An experimental and qualitative dental microwear study by Puech et al. (1988) used a comparative sample of fluorosed and normal teeth. The sample consisted of: 10 Sabra rats, five given fluoridated drinking water; 10 permanent teeth extracted from people living in an endemic fluorosis region of Morocco; and a control group of extracted teeth from a non-fluoridated European population. After the teeth were cleaned, their lingual surfaces were scored with a high-speed tungsten burr. Examination of the specimens with SEM at high magnifications revealed no differences between the experimental and control samples of rat teeth. However, the human fluoridated teeth exhibited more abrasion (e.g., chipping) than the control group. The authors attributed the subsurface defects to the less resilient and more brittle fluorotic enamel in subsurface layers of the teeth. Comparison with a premolar tooth from Australopithecus boisei (Peninj) revealed features similar to the fluorosed human teeth. The low magnification micrographs that illustrate this phenomenon in the Peninj specimen are not convincing, however, and the authors' inference that A. boisei resided in fluoride-rich areas near volcanoes (Puech et al. 1988) should be accepted cautiously.

Qualitative Microwear Studies of Prehistoric Human Teeth

Most microwear studies of human teeth from prehistoric cemetery sites have been qualitative in nature (Blaeuer and Rose 1982; Harmon and Rose 1988; Højgaard 1985; Hojo 1989; Lukacs and Pastor 1988, 1990; Marks et al. 1988; Pastor 1986, 1990a, 1990b, 1992, n.d.; Pastor and Johnston 1992; Pedersen and Scott 1951; Power and O'Sullivan 1988; Rose 1984; Rose and Harmon 1986; Rose and Marks 1985; Rose et al. 1982; Ryan 1980; Ryan and Johanson 1989; Puech 1979; Puech et al. 1983b; Shkurkin et al. 1975).

Shkurkin et al. (1975) may have been the first investigators to suggest that paleodietary reconstruction could be derived through the study of microscopic wear features on the teeth of prehistoric individuals. Unfortunately, this early attempt at dental microwear analysis was premature, because dentine apparently was mistaken for enamel (Walker and Teaford 1989).

As discussed earlier, Pedersen and Scott (1951) observed microscopic wear features (pits and scratches) on the surfaces of anterior and posterior permanent teeth from prehistoric Alaskan Eskimos, and living West Greenland natives and American whites. The latter group exhibited only slightly fewer microscopic scratches than did the other two ethnic groups. Microscopic pits ("micro-pits") were observed on ail teeth, but in higher frequencies on the teeth of the Alaskan Eskimo and West Greenland groups. However, the authors concluded that the pitting was developmental in origin, because it was present even in unerupted teeth. Also, the size of these pits (20-50 µm in diameter) is too great to be attributed to the ends of dentinal tubules. However, it is difficult to discern the morphology of these features from the micrographs (120x), because the metal-shadowed collodion replicas of tooth surfaces are negative impressions, which reveal all features in an inverted fashion.

A portion of Ryan's dissertation (1980a; also Ryan and Johanson 1989:257) was devoted to prehistoric Eskimo and Late Woodland Indian anterior microwear. Microwear

observed on the Eskimo anterior teeth consisted of labiolingually oriented striae and smoothed flaked edges, which Ryan suspects were produced by the crushing and holding of hard materials, producing microflaking, and from gritty materials being pulled across the tooth surfaces.

Harmon and Rose (1988) utilized four qualitative categories of microwear patterns (compression fractures, polish, striations, and striation margin morphology) which effectively discriminated between several (13) prehistoric skeletal populations from the southeastern United States. However, most sample sizes for individual skeletal populations were very small. For example, only three lower second molars were used from the Powell Canal population (Blaeuer and Rose 1982). Therefore, qualitative descriptions of microwear patterns derived from these populations may not adequately account for the intrapopulational variation. Nevertheless, the microwear studies by Rose and colleagues (e.g., Rose et al. 1982; Rose 1984; Rose and Marks 1985; among others) represent a valuable body of work for comparative analysis with other prehistoric archaeological samples.

Compression fractures appeared at low magnification as roughly oval depressions, with approximately equal widths and lengths. At 10-25 magnifications they were defined as 'pits.' Many other investigators have observed pitting on enamel surfaces, as a result of the crushing of very hard and usually small particles during mastication. Among the prehistoric cultures from the southern and southeastern United States, the presence of compression fractures on molar teeth was associated with the consumption of nuts (e.g., hickory nuts). The presence of many nut hulls in coprolites from some sites indicated that the occupants did not exclude hard items from their diets (Marks et al. 1988).

Polish was defined as any area of flat, featureless enamel. Polishing of an enamel surface was attributed to a high proportion of unprocessed vegetable fibers in the diet. Polish has also been noted as a distinctive feature by other investigators (e.g., Puech et al.

1983b; Rensberger 1978; Ryan 1981; Walker et al. 1978), but these other analyses have often been at a much lower magnification. A 'polished' surface at relatively low power may not appear the same (i.e., it may be rougher) at higher magnification. However, Rensberger (1978) has observed polish, defined as a lack of texture, on rodent cheek teeth at even very high magnifications. This would imply that in some taxa polished enamel does not change in observable surface characterstics with the levels of magnification used for examination, but it is unclear whether the polished surfaces described by Rose and colleagues would still appear featureless at low magnification.

As defined by Harmon and Rose (1988), striations are linear depressions with well defined troughs, and they are longer than they are wide. Striations were divided into categories of small, medium and large on the basis of measured width (mm). But these dimensions do not lend themselves to comparison without conversion into a more standard increment (micrometers) and without rescaling for another magnification. The presence of striations on the occlusal surfaces of molar teeth was attributed to the use of stone utensils by prehistoric peoples to process vegetable fiber, and hard items such as nuts and berries (e.g., Rose and Marks 1985).

Striation margin morphology was offered as a novel category of qualitatively observing striations. These were considered in terms of relative sharpness, roughness, roundness and smoothness of the scratch margins and troughs. Scratches can range along a continuum of these qualities. A fifth qualitative category, mean striation frequency, was considered by the authors to be a broad indicator of the proportion of grit in the diet. Harmon and Rose (1988) considered the following three features in relation to mean striation frequency: (1) the proportion of sharp striations present, which could indicate the approximate age of the scratch (i.e., recent or old); (2) the degree of polishing; and (3) the attrition rate as scored by the Scott, Murphy or other method. They suggested that the use of these features in unison provided a 'more sensitive' indicator of the contribution of

dietary grit contamination, because a large concentration of grit and/or a high rate of attrition can skew results based on only one of the above features.

Harmon and Rose's study cannot be confidently compared to others (e.g., Teaford's, Gordon's, Pastor's) because their SEM assessment was at 1500x. In other words, caution is required when relying on the descriptions of patterns for the three to four prehistoric cultures (Blaeuer and Rose 1982) in a comparative analysis of dental samples from other prehistoric populations. Also, they used original whole teeth for SEM assessment, but such high magnification with replicas may run the risk of confusing casting artifacts (e.g., bubbles) with true wear features (e.g., pits).

Puech and colleagues (1983b) conducted a semi-quantitative examination of the dental attrition (Scott scores) and dental microwear of predynastic and dynastic Nubians and Egyptians. However, they used a low power of resolution (100x) with normal transmitted light microscopy and examined only the buccal surfaces of teeth, which limits comparability with the present study as well as others. This study also did not rely on Puech's (1976) graphical depiction method, in which a star-shaped diagram is produced to represent scratch orientation. Very few striations were present on the Egyptian teeth, especially the upper first molars, but the authors were not particularly clear in their description of "blunt furrows." Generally, the teeth exhibited a polished appearance with few striations. Puech and his colleagues (1983b) attributed this appearance to either the consumption of food with very fine abrasive particles or to chewing vegetable masticatories (e.g., papyrus) containing silica bodies (phytoliths). The authors also emphasized that possibly because of grit in the diet, two different cultures consuming two entirely different sets of food items may show similar microwear patterns.

Using SEM, Ryan (1980) compared the dental microwear patterns of anterior teeth of Western European and Near Eastern Neanderthals, precontact Eskimos from Point Hope, Alaska, and African pongids. The microwear patterns of Neanderthals and Eskimos

were quite similar, with chipped, deeply scarred and heavily pitted occlusal and labial surfaces. In contrast, African ape microwear consisted of polishing and scoring with fine wear striae oriented labiolingually. Ryan believed the ethnographically documented Eskimo use of their anterior teeth for nondietary activities suggests that Neanderthals may have used their anterior teeth for clamping and holding hard abrasive objects.

Højgaard (1985) examined the dental microwear patterns, with SEM at 200x, on the upper one-third of the buccal surface of mandibular second molars of prehistoric people from the third millennium B.C. sites of Wadi Jizzi and Hafit. She used the methods of Puech and his colleagues, plotting orientations and length of striations in "star" diagrams. She showed that the Wadi Jizzi population had a long star diagram (i.e. many vertical striae were present), while the Hafit population had more horizontal striations and broad short star diagrams. She concluded that the Wadi Jizzi people ate mostly meat, while the Hafit people consumed mostly vegetable foods.

Puech (1979) contended that only the buccal surface of a tooth preserves the microscopic features of abrasion (e.g., striations). Buccal surface striae may be produced as the food bolus is compressed against the buccal surface by the cheek muscles during chewing. According to Puech, the occlusal surfaces of a tooth are more affected by attrition, because of the masticatory forces exerted while the opposing teeth are in centric occlusion. He also suggested that buccal surfaces are better indicators of non-masticatory tooth use. However, Puech has never presented convincing evidence that the occlusal surface is not as good or even a better indicator of microwear produced by contact with foods or extrinsic abrasives during normal mastication. His basic analytical tool is the depiction of scratch orientations in star-shaped diagrams. Although he assesses the length of scratches, this is done at low magnification (50x) with a light microscope. However, the natural rounding of the buccal surface of a molar tooth and the minimal depth of field provided by the microscope would inhibit the accuracy of such measurements. Also,

perikymata may have provided enough topographic relief on the buccal surfaces to have altered the travel of a grit particle as it scored the enamel. Thus, the actual or potential dimensions of scratches may not be represented on the buccal surface. Puech's method also includes separating out scratches with the greatest depth, because it is believed these are caused by non-masticatory forces. However, without three-dimensional analysis (e.g., stereology) of scratch morphology it is difficult to accurately determine scratch depth (Boyde 1974).

Puech (1979:592) concluded that a general trend exists in the buccal surfaces of prehistoric hominine dentitions for "an increasing number of horizontal and a decreasing number of vertical grooves from the most ancient (Homo erectus) to the most recent (H. sapiens sapiens) specimen, with an average decrease in the length of the grooves corresponding to a progressively decreasing degree of effort produced by the teeth in the course of human evolution." Presumably, this chronological trend toward increasing reliance on processed vegetable foods in the diet decreased the number of chewing strokes and lateral excursions of the lower jaw. Puech's results are intriguing but should be accepted as preliminary, because of the small size of samples and the lack of control of postmortem wear.

Preliminary studies by Hojo (1989) and Pastor (1986) used very small samples of prehistoric human mandibular canine and molar teeth. Hojo's qualitative analysis of the dental microwear patterns for two prehistoric Japanese populations revealed numerous long wide lingual-buccal oriented scratches on teeth from a Late Stone Age (4000 B.P.) site. Fewer and narrower scratches were found on teeth from an early agricultural (150-200 B.P.) Japanese population. These differences indicated that the number and size of abrasive particles declined through time. Pastor (1986) studied the microwear and microstructural defects of teeth from neolithic and chalcolithic Mehrgarh (Periods I and III), Pakistan. Molar teeth from the chalcolithic site exhibited a large number of small pits and

fine striations, whereas canine teeth from the earlier neolithic site exhibited far fewer and coarser scratches. These microwear differences were undoubtedly due to the different functional roles of the two tooth classes, but as with the Japanese groups may also be indicative of a decrease in the size of dietary abrasive particles through time.

The work by Lukacs and Pastor (1988, 1990) on the cultural modification of tooth surfaces was reviewed previously in the attrition section of this chapter. Recently, qualitative and preliminary quantitative analyses of dental microwear in prehistoric South Asian populations have been undertaken by Pastor (1990a, 1990b, 1992, n.d.), and Pastor and Johnston (1992). Microwear patterns, based on scratch morphology and the texture of the enamel fabric, were characterized for the mesolithic site of Mahadaha (Pastor and Johnston 1992), chalcolithic Mehrgarh (Pastor 1990a, 1990b), and the Bronze age site of Harappa (Pastor, n.d.). Microwear differences were found between each of these groups, with the most dramatic difference occurring between the mesoltihic and bronze age groups. These studies have been elaborated upon and incorporated into the present study (see Chapter V), so further review is not presented here.

Quantitative and Systematic Analyses of Prehistoric Human Teeth

Quantitative and systematic analyses of prehistoric human microwear have been few in number, to date (Borgognini Tarli et al. 1989; Bullington 1988, 1991; Fine and Craig 1981; Gordon 1986 1990; Molleson and Jones 1991; Pastor 1990c, 1991; Teaford 1991; Walker et al. 1987). Gordon (1986) was the first investigator to quantitatively assess prehistoric populations, in which ethnographic information for diet and food preparation behaviors is available. She emphasized that no adequate control populations had previously been studied where the prehistoric diet could be corroborated. Her study of Zuni and Eskimo dentitions revealed marked differences in microwear patterns. The maize-consuming Zuni exhibited microwear that is coarse, with broad scratches, large pits and

much featureless surface roughening. But the Eskimo, who consumed primarily marine mammals, exhibited microwear showing many finer scratches and very abundant small pits. Other differences noted were the relative proportions of pits and scratches, and relative orientations of scratches. However, feature densities were found to be fairly similar. Gordon (1986) further emphasized that the differences are not surprizing, considering the marked differences in their diets, and that the next step in the analysis of prehistoric human microwear is to refine the level of analysis by studying populations with less extreme differences in dietary specializations.

A more recent quantitative dental microwear analysis by Gordon (1990) incorporated multivariate and univariate techniques for quantitative microwear data from molars of several historic aboriginal populations from the New World. The samples included maize agriculturalists, mixed hunter-gatherers, and marine mammal hunters. Ethnographic, stable isotope, and trace element data were also available for most of the samples. Results of the analysis confirmed that variability in dental microwear patterns reflected dietary differences between the samples, rather than differences in food processing and acquisition techniques.

Fine and Craig (1981) followed the research protocol developed by Puech (Puech 1976, in French; Puech et al. 1980) with modifications. Transmitted light microscopy at relatively low magnification was used in this study to examine primarily the buccal surfaces of epoxy replicas of the entire posterior dental arcade (premolars through third molar). At a resolution of 40x, the location and distribution of striae were noted with regard to their vertical disposition on three areas of the buccal surface: an occlusal location, mid-buccal area, and the cervical zone. Also noted were whether the striae possessed a diffuse or focal arrangement, and how they were aligned with regard to the occlusal plane and/or the cuspal inclines. Since these observations produced nominal data, they were analyzed using chi square. The second level of analysis used by Fine and Craig (1981) consisted of counting

all scratches observed at a resolution of 100x in one area of the buccal surface of each replica. A graduated reticule was used to facilitate the assessment. Only vertical and horizontal striations were counted, and a ratio scale was computed of the total horizontal versus vertical striations. Correlation coefficients were calculated and logarithmic transformed data were submitted to linear regression and analysis of variance.

Their sample consisted of dentitions from Greenland Eskimo, Northwest Asiatic Indians, and Australian Aborigines. Provenience information was not provided for any of these groups, although it is presumed that they were all derived from historic periods. Their analysis confirmed that striations are a normal feature of the buccal surface near the occlusal margin, and that the microwear is produced as these surfaces come into contact with food during mastication. However, the orientations of buccal surface striations may be influenced by the consistency and texture of the foods forming the bolus in a non-systematic (irregular) fashion (i.e., scratch orientation is highly variable). This is evident in the linear regression curves and non-significant correlation coefficients for the Northwest Asiatic Indian group, whereas the other two populations showed significant within-group correlations. Possibly, the presumed diet of sticky, high carbohydrate foods for the Indian group would hinder travel of the bolus of food from occlusal surfaces onto buccal surfaces during mastication. However, analysis of variance showed no significant differences between populations. They conceded that small sample sizes, the limitations of light microscopy, and the lack of ethnographic dietary data hindered making any substantive dietary inferences with regard to other populations. They recommended that future research consist of quantitative analyses of the orientation of striations located on occlusal wear facets, and their association with macroscopic tooth wear.

Borgognini Tarli and her colleagues (1989) used low magnification optical microscopy in a semi-quantitative dental microwear analysis of an Italian (Sicily) mesolithic skeletal series. Preliminary to the analytical portion of the paper, they presented a useful

flow chart for defining the contribution of non-alimentary tooth use to tooth wear in human and non-human primates. As with the work of Rose and colleagues (e.g., Blauer and Rose 1982; Harmon and Rose 1988; among others), the authors also provided a detailed qualitative description of dental microwear patterns and feature morphology observed in the mesolithic remains. Although the features are reputed to be morphologically similar to those determined through SEM analyses, this is not necessarily true for analytical studies relying on considerably higher resolving power (e.g., 500x). Of interest also is the integration of data from trace element analyses with those from the dental microwear analyses. Results from the latter showed that alimentary and extra-alimentary tooth use were responsible for specific types of microwear features. For example, the authors suggested that the presence of large marginal grooves on anterior teeth, and the unequal distribution of these within the sample, could be attributed to the preparation of cordage or other task activity, in which vegetable fibers are grasped and pulled powerfully through the teeth. Alimentary tooth use was implicated for other dental microwear features, such as fine striations, small and large pits, occlusal flakes, and polished facets. For example, Borgognini Tarli and colleagues attributed the presence of large occlusal pits and flakes on many of the teeth to the ingestion of hard contaminants in the food. Such microwear features, in combination with faunal remains of molluscs and high zinc concentrations in bone, led the authors to conclude that this mesolithic population relied to a significant extent on shellfish to supplement their animal protein intake from wild game.

A semi-quantitative dental microwear analysis was undertaken by Bullington (1988, 1991) on deciduous teeth from a large mixed-age sample (n = 36, 6-27 months of age) of juvenile individuals from Middle Woodland and Mississippian populations from the lower Illinois River Valley. Incisal edges and cusp tip facets of maxillary or mandibular incisors and mandibular first molars, respectively, were analyzed with SEM at 500x. Qualitative and quantitative microwear data, collected by Bullington from electron micrographs, were

analyzed statistically to determine age-related changes in microwear and the association of microwear parameters with prehistoric diet and food preparation technology. For instance, each micrograph was scored for enamel "surface characteristics," judged qualitatively, on a scale from one to five (stages I-V). Data on feature frequencies, but not on feature dimensions, were also collected.

Results from her study indicated that the frequency of microwear features (pits and proportion of pits) on deciduous teeth increased with age and exposure to wear, whether based on age of the individual or the erupted age of the tooth. In other words, higher frequencies of pits or proportion of pits were characteristic of older individuals and/or teeth. Not surprisingly, an absence of microwear features was characteristic of unerupted teeth, and no differences were found between the cultural groups for age at first appearance of microwear. All five wear stages were found on molar cusp tips, whereas only the first three stages were found on incisal edge surfaces. Strong correlations were found between the five stages and both age and erupted age. Bullington also investigated the relationship between deciduous microwear and cultural affiliation, finding that age-related microwear trends but not enamel surface differences were present. Few significant differences were found between specific microwear variables and cultural group when compared by individual age or erupted age. However, total feature frequencies of very young Middle Woodland juveniles were higher than for Mississippian teeth. Within the Mississippian subsample, however, many of the feature frequency variables significantly increased with age and/or erupted age. Based on these and other results, Bullington concluded that the Middle Woodland juvenile diet was harder and more varied in physical consistency than the diet of Mississippian juveniles. These conclusions were consistent with archaeological evidence (e.g., ceramics, paleobotany) from the Middle Woodland period for the consumption of hard nuts and starchy seeds, which had been cooked minimally at most. In contrast, Mississippian inhabitants used maize as a dietary staple and consumed

proportionately fewer nuts and hard starchy seeds, which were probably softened by boiling prior to consumption.

In a review article, Teaford (1991) used a quantitative dental microwear analysis of a prehistoric population from the southeastern United States coast to illustrate the utility of microwear analyses for paleodietary reconstruction. A standardized microscopic protocol was used to analyze the microwear on maxillary first molar teeth from three mixed-age skeletal samples: a precontact group (400 B.C.-A.D. 500) that relied on hunting and gathering of marine foods; an early contact group (A.D. 1607-1680); and a late contact group (A.D. 1686-1702). After the establishment of Spanish missions, the later groups are reported to have become increasingly dependent upon maize agriculture and less reliant on marine resources. Teeth of the precontact group had significantly more pits and wider scratches than either of the agricultural groups, although the scratch width for the early contact site was intermediate between the other two sites. The average pit widths for the precontact group also showed significantly less variation. Teaford interpreted these results to indicate that the hunter-gatherers were regularly ingesting large hard abrasive particles (e.g., sand grains), probably as contaminants in their food. In contrast, the use by late contact people of wooden metates and pounders to process maize probably prevented the introduction of extraneous grit into the corn flour. Therefore, these agricultural peoples experienced decreased enamel pitting on their teeth.

Molleson and Jones (1991) investigated microwear differences on deciduous and permanent teeth from a mesolithic level (12,000-10,000 B.P.) and two neolithic levels (10,000-7000 B.P.) of Tell Abu Hureyra, Syria. This semi-quantitative low-power SEM study, collected quantitative and descriptive data (microwear parameters, including means and standard deviations) from shearing and crushing/grinding 'regions' on occlusal surfaces. Subjective comparison of the mean values was undertaken, but with no statistical analysis of the data. Sample sizes were fairly small, especially for the mesolithic sample

which contained a single permanent tooth. Nevertheless, the authors offered some intriguing predictions and interpretations about microwear differences between the groups, and the association of these differences with changes in horticultural practices, diet, and culinary practices. For the mesolithic sample, they suggested that the low density of features and pits, most of which were of small diameter, were associated with the consumption of a relatively soft diet of small seeds that presumably could be swallowed with little initial crushing. By contrast, the higher density of features and especially medium-size pits for the early neolithic group was associated with a harder diet of medium grains, which required processing with basalt mortars and pestles. For the late neolithic group, the variability in feature density and the larger pits on the teeth may indicate a more variable diet, because similar grains were found in both neolithic levels.

The pit diameters of the neolithic Syrian groups (Molleson and Jones 1991:531) are markedly smaller than those on teeth of precontact or contact groups from the southeastern United States (Teaford 1991:353), although methodological differences in the two studies make comparison difficult. Because similar methods were used, Pastor's (1990c, 1991) quantitative work on prehistoric South Asian groups can be more confidently compared with Teaford's (1991) southeastern United States data. Quantitative data from the South Asian samples are presented in Chapter VI, and comparisons with other studies are discussed in Chapter VII.

CHAPTER III

THE ARCHAEOLOGICAL SAMPLES

Introduction

This chapter discusses the archaeological provenience (context), prehistory, and physical anthropology of the four prehistoric cemetery sites from which dental samples were obtained for microwear analysis. In diachronic order, these sites consist of the mesolithic Ganga Valley site of Mahadaha, located in Pratapgarh District of Uttar Pradesh, north India; the neolithic (MR3) and chalcolithic (MR2) phases of Mehrgarh, a site located near the Bolan Pass in Baluchistan Province, Pakistan; and the bronze age site of Harappa, located along a dry channel of the Ravi River, Punjab Province, in eastern Pakistan.

The site of Harappa, the type site of the Harappan civilization, has been studied for at least 100 years and is very well documented. The literature on Harappa covers a broad spectrum of theoretical constructs, and it can be found in widely available monographs and edited volumes, as well as textbooks of archaeology (e.g., Fagan 1977). Such a situation is certainly not as true for the literature on the Indian mesolithic, or even some of the literature regarding the pre-Harappan cultures of the greater Indus Valley, such as Mehrgarh. The much briefer time since discovery of the sites of Mahadaha and Mehrgarh has certainly contributed to the more limited analysis, to date, of these prehistoric cultures. For example, osteological analyses have yet to be completed or fully reported for neolithic Mehrgarh (MR3) or chalcolithic Mehrgarh (MR2). Therefore, the following review of the archaeological literature on Mahadaha will be brief, but will include many articles or monographs not readily available outside of Indian academic circles. However, the several periods at Mehrgarh, including Periods I and III, have been fairly well documented but not

always in literature easily available to American scholars. Consequently, a very thorough review of the literature pertaining to Mehrgarh is provided. The subsequent review of the archaeological literature on Harappa will be brief, but will encompass an overview and provide citations for more definitive sources with regard to specific topics, such as chronology, archaeological evidence for burial context and ritual offerings, tool assemblages and other archaeological evidence for food processing and diet, and the physical anthropology (including the osteology, paleopathology, and morphometrics).

Mahadaha

Location and Chronology

Beginning in 1969, intensive archaeological exploration of parts of the Upper and Middle Ganga Valley of northern India has been conducted regularly by the Department of Ancient History, Culture and Archaeology, University of Allahabad (Varma 1989). More than 40 sites have been discovered during these explorations. Sites range in complexity from small seasonal encampments in the Vindhyan Hills to permanent or semi-permanent village sites along the Ganga River and its associated lakes. The latter represent "pre-agricultural settlements" belonging to the mesolithic period, and include the cemetery sites of Damdama, Mahadaha, and Sarai Nahar Rai, located in Pratapgarh District of Uttar Pradesh (Varma 1989:55). Mesolithic age sites are ubiquitous throughout the Indian subcontinent, and are found in environments ranging from the Ganga Valley in the north to Sri Lanka in the south, and from coastal islands near Bombay east to coastal sand dunes near Madras (Kennedy 1984). Cultural traits that are common to all Indian mesolithic sites include: geometric and non-geometric microlithic tools; the bow and arrow; domestication of the dog; hunting of large game; and occupation of rockshelters, open-air camps and lake shores (Kennedy 1984; Sharma 1975; Varma 1985) (Figure 3.1).

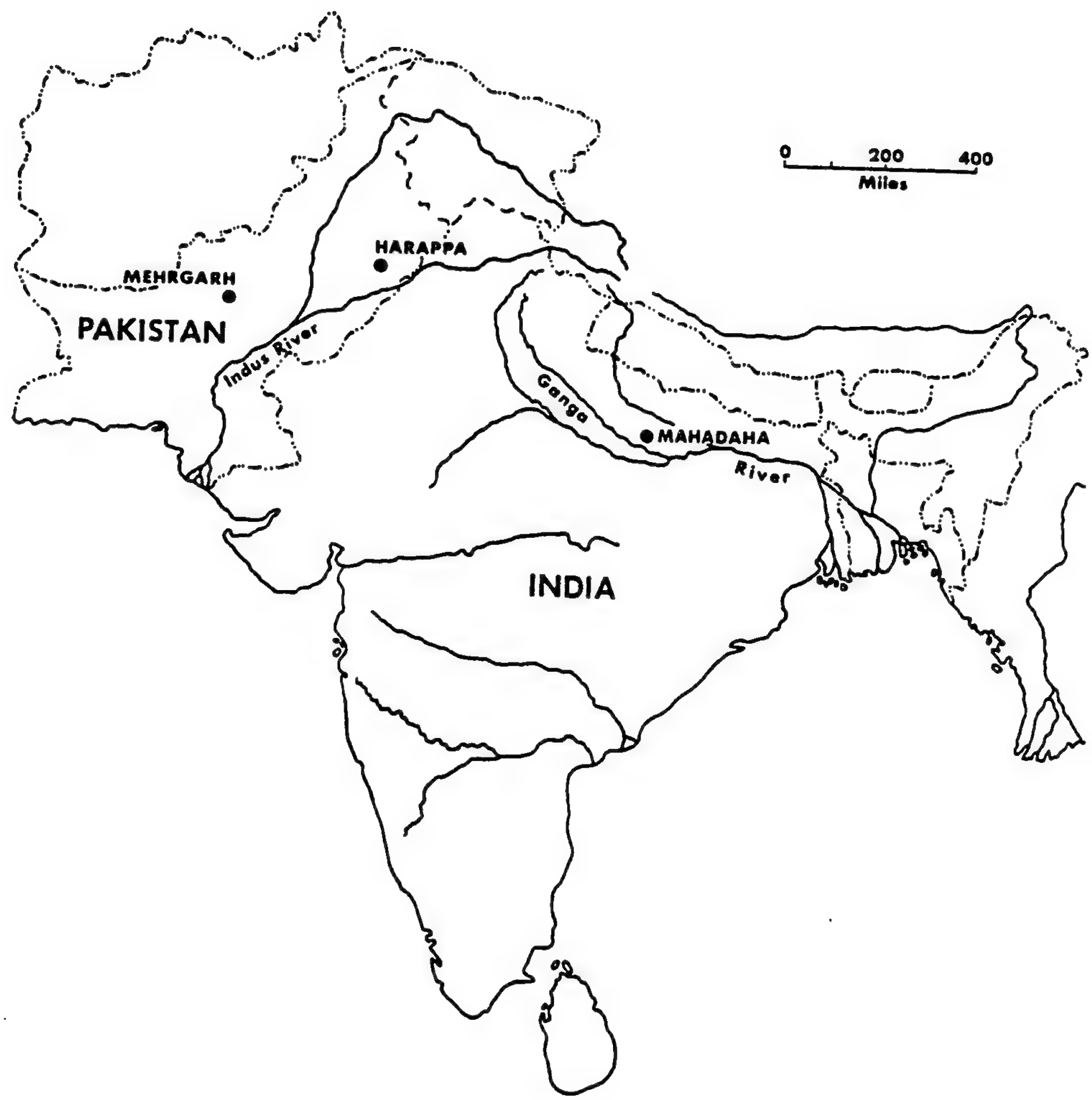

Figure 3.1. Map of Indian Subcontinent with Locations of Archaeological Sites Used in Study.

A detailed summary of mesolithic cultures of India and Pakistan has been provided by Sankalia (1974), who has long been a proponent of archaeological investigations of the earliest human occupation of the Indian subcontinent. A recently published volume edited by Kennedy and others (1991) comprehensively addresses the site of Mahadaha from the perspective of its archaeology, paleoecology, and physical anthropology. Langhnaj and Sarai Nahar Rai were the first discovered and extensively documented of the Indian mesolithic sites. The physical anthropology of the cemetery site of Sarai Nahar Rai has been reported by Dutta (1973, 1984b). Pal (1988) and Varma and colleagues (1985a) have documented the archaeological assemblage and provided a preliminary report on the burial position of human remains and associated finds at Damdama. These two sites will be discussed very briefly, because they are companion sites to Mahadaha.

Few radiocarbon dates are available from the mesolithic sites of the Ganga Valley, and none are presently available from Damdama (Varma 1989). A single radiocarbon date obtained from human skeletal material of Sarai Nahar Rai places this mesolithic site at 10,050 ± 110 years B.P. (8400 B.C.). Mahadaha is suggested to be of a similar antiquity because the alluvial fill of both sites belongs to the same early Holocene horizon (Dutta 1984b; Varma 1989). Based on the thick alluvial fill of Damdama, Varma (1989:58) concluded that the mesolithic period of the Ganga Valley should be placed in a time frame from 10,000 B.C. to approximately 4000-3000 B.C.). However, recently-obtained calibrated radiocarbon dates from Mahadaha range in age from 885 B.C. to 2675 B.C., yielding an estimated occupation date of 3000-1000 B.C. (Possehl and Rissman 1992). Consequently, these authors believe that Mahadaha and perhaps Sarai Nahar Rai may be much younger than originally thought. Nevertheless, Mahadaha is still technoculturally a mesolithic site, based on the artifact assemblages (discussed below).

Mahadaha was first discovered by workmen constructing a canal, which disturbed several prehistoric human burials and eventually destroyed a large portion of the cemetery

site. During the late 1970s, archaeologists under the direction of the late G.R. Sharma excavated the remainder of the cemetery and recovered human and animal bones from fill in the canal dump (Sharma, et al. 1980). Mahadaha is located five kilometers north of Patti and 31 kilometers northeast of the city of Pratapgarh in the district of Pratapgarh, Uttar Pradesh. The site area measures approximately 8,000 square meters, and the habitation deposits extend 60 centimeters below the surface (Varma 1989). It is located along the shoreline of an ancient oxbow (horseshoe) lake, now under cultivation, which was originally associated with a channel of the Ganga River. This lake was created when a meander channel of the original river bed was cut off after the river shifted its course. Seasonal flooding of the Ganga River, which still presently occurs, produced annual inundation and recharge of this and other lakes (Sharma 1975; Sharma, et al. 1980). In fact, approximately 100 'Stone Age' sites have been discovered on the banks of such ancient lakes in the Ganga Valley (Sharma 1975).

Three areas have been recognized within the Mahadaha site boundaries: a centrally-located habitation area with associated graves containing human remains ('cemetery-cum-habitation' area); a butchering area located to the east of the principle settlement; and the lake area from which many animal bones were recovered (Sharma, et al. 1980). These authors also note that no burials were located within the butchering area, and that the haphazard placement of hearths, such that some intrude into the burials, is indicative of little or no planning having taken place at Mahadaha. In contrast, none of the hearths at Sarai Nahar Rai encroach upon the burials, which are reported to be clearly separated from the habitation area (Sharma, et al. 1980). The cemetery area excavated in 1978 measured 24 x 9 meters (Kennedy 1984). Based on the disinterred human bones recovered in the fill of the canal, Sharma and colleagues estimate that at least 17 skeletons were destroyed during digging of the canal. A total of 28 graves containing 35 skeletons were eventually excavated, some of which were associated with 25 circular or oval pit hearths (Kennedy

1984; Varma 1989). Based on additional skeletal remains from disturbed burials, Varma (1989) estimates that 58 individuals were originally interred in the Mahadaha graves. Listed in Table 3.1 are the age at death and sex of the Mahadaha individuals from which molar impressions were collected.

Archaeology

Four phases have been described for the evolutionary sequence of the mesolithic microblade industry in the Indian subcontinent. Mahadaha is characterized by two phases of this sequence: non-geometric microliths; and geometric microliths, both of which are unassociated with pottery (Varma 1985). Generally, the microlithic artifacts recovered from rockshelters in the Vindhyan Hills, to the south of Mahadaha, are larger than those from the open-air Ganga Valley sites (Sharma 1975). The author suggests that the much smaller size of the Mahadaha microliths is a consequence of the reworking of tools fashioned originally from core material obtained from the Vindhyas. Apparently, local sources of raw lithic material were absent from the area surrounding Mahadaha (Sharma 1975; Varma 1985). In addition, Misra and Pal (1980) suggest that Mahadaha is older than Sarai Nahar Rai (8395 B.C.) because of the earlier and presumably more primitive style of microliths at Mahadaha.

A section in the monograph by Misra and Pal (1980) is devoted to an analysis of the microlithic assemblage of Mahadaha. These authors state that finished tools are relatively scarce, because of the distance from the source of the raw material in the Vindhyan Hills, and also to many of the tools having been lost during use. In general, the lithic industry at Mahadaha is characterized as a "blade dominated industry", in which the tools are of small size and manufactured locally (Misra and Pal 1980:105). Microlithic tools recovered from Mahadaha consist of: parallel sided blades; projectile points; blunted back blades; lunates; scrapers; triangles; notched blades; borers and trapezes (Misra and Pal 1980). These tools

Table 3.1. Sample of Permanent Mandibular Molar Teeth from Mesolithic, Neolithic, Chalcolithic, and Bronze Age Sites of South Asia

Specimen	Lab No.	Original/ Impression*	Molar Type	Age category/Sex of individual	Provenience	Site
A1	01	O	LM1	Adult/Male	MR2-42	Mehrgarh
A2	02	O	LM2	Adult/Male	MR2-42	Mehrgarh
B1	03	I	LM1	11 yr. old/Sex?	H87-37	Harappa
B2	04	I	LM2	11 yr. old/Sex?	H87-37	Harappa
C1	05	O	RM1	16 yr. old/Female	MR2-60	Mehrgarh
C2	06	O	RM2	16 yr. old/Female	MR2-60	Mehrgarh
D1	07	I	LM1	20 yr. old/Female	H87-60	Harappa
D2	08	I	LM2	20 yr. old/Female	H87-60	Harappa
E1	09	I	LM1	22 yr. old/Female	H87-72	Harappa
E2	10	I	LM2	22 yr. old/Female	H87-72	Harappa
F	11	O	RM1	4 1/2 yr. (unerupt?)	MR2-36A	Mehrgarh
G1	12	I	RM1	30yr. old/Female	H87-85	Harappa
G2	13	I	RM2	30yr. old/Female	H87-85	Harappa
H1	14	O	RM1	Young Adult/Male	MR2-34	Mehrgarh
H2	15	O	RM2	Young Adult/Male	MR2-34	Mehrgarh
I1	16	O	LM1	Adult/Female	MR2-45	Mehrgarh
I2	17	O	LM2	Adult/Female	MR2-45	Mehrgarh
J1	18	O	RM1	11-12 yr. old/Sex?	MR2-46	Mehrgarh
J2	19	O	RM2	11-12 yr. old/Sex?	MR2-46	Mehrgarh
K1	20	I	RM1	11-15 yr. old/Sex?	H87-60	Harappa
K2	21	I	RM2	11-15 yr. old/Sex?	H87-60	Harappa
L1	22	I	LM1	30yr. old/Female	H87-85	Harappa
L2	23	I	LM2	30yr. old/Female	H87-85	Harappa
M	24	O	RM1	Adult	MR3-35	Mehrgarh
N1	25	O	RM1	Adult (young)	MR3T-S36	Mehrgarh
N2	26	O	RM2	Adult (young)	MR3T-S36	Mehrgarh
U1	34	I	RM1	Young Adult/Male	MDH-2	Mahadaha
U2	35	I	RM2	Young Adult/Male	MDH-2	Mahadaha
V1	36	I	RM1	Young Adult/Male	MDH-11	Mahadaha
V2	37	I	RM2	Young Adult/Male	MDH-11	Mahadaha
W1	38	I	LM1	18 yr. old/Male	MDH-1	Mahadaha
W2	39	I	LM2	18 yr. old/Male	MDH-1	Mahadaha
X1	40	I	RM1	Young Adult/Male	MDH-15	Mahadaha
X2	41	I	RM2	Young Adult/Male	MDH-15	Mahadaha
Y1	43	I	RM1	Adult/Male	MDH-26	Mahadaha
Y2	44	I	RM2	Adult/Male	MDH-26	Mahadaha
AA1	45	I	RM1	29 yr. old/Female	H87-145	Harappa
AA2	46	I	RM2	29 yr. old/Female	H87-145	Harappa
BB1	47	I	RM1	19 yr. old/Male	H88-191	Harappa
BB2	48	I	RM2	19 yr. old/Male	H88-191	Harappa

Table 3.1. (Continued).

Specimen	Lab No.	Original/ Impression*	Molar Type	Age category/Sex of individual	Provenience	Site
CC1	49	I	RM1	18 yr. old/Male	H88-200	Harappa
CC2	50	I	RM2	18 yr. old/Male	H88-200	Harappa
DD1	51	I	LM1	18 yr. old/Male	H88-200	Harappa
EE1	52	I	RM1	25 yr. old/Female	H88-197	Harappa
EE2	53	I	RM2	25 yr. old/Äemale	H88-197	Harappa
FF1	54	I	LM1	25 yr. old/Female	H88-197	Harappa
FF2	55	I	LM2	25 yr. old/Female	H88-197	Harappa

*Note: O indicates that the original whole tooth was available in the laboratory; I indicates that only a dental impression was available.

are fashioned from various materials, such as chert, chalcedony, carnelian, agate, quartz and crystal, with cherty material being predominant.

Many tools fashioned from bone were recovered from Mahadaha, presumably because of the local unavailability of lithic material (Misra and Pal 1980). Split tubular animal bones and horn cores from sheep, goat, and occasionally stag were used to fashion arrowheads which were pointed at both ends. The Mahadaha bone assemblage also consisted of points sharpened at only one end, knives and blades, chisels, scrapers and saws (Misra and Pal 1980). According to these authors, the first antler ornaments from the Indian mesolithic have apparently been found at Mahadaha. These consist of finished and unfinished earrings and necklaces recovered from three graves.

In addition to the microlithic and bone artifacts, many fragments of large groundstone artifacts ('stone objects') were discovered at Mahadaha and nearby sites. These tools include: sandstone querns (metates), mullers (manos), anvils, muller-cum-anvil, hammer stones, and other groundstone tools (Sharma et al. 1980; Varma 1985). At Mahadaha, a large proportion (64%) of these many groundstone artifacts (n = 301) were querns, with an even larger proportion at Damdama (Varma 1989:56). Lithic artifacts described as sharpeners and sling balls were also recovered at Mahadaha (Misra and Pal 1980). Because querns and mullers were present in the highest frequencies for all of the stone objects, vegetal food processing is considered to have been an important activity at Mahadaha (Misra and Pal 1980). Based on the same evidence, Varma (1989:56) concludes that "their concentration in such high numbers indicates the dependence of the people on vegetal food."

Varma (1985) describes the microliths as multipurpose tools, depending on the method by which they were hafted. According to the author, the procurement of vegetal foods was likely undertaken through the use of blunted back blades and lunates, while scrapers were used for processing bark and hides. However, microlithic points in the

shape of triangles and trapezes were probably used for hunting and defense purposes (Varma 1985). Sharma (1975) believes that these microliths were hafted to shafts of arrows for use with a bow, a weapon commonly used during the Indian mesolithic. Varma (1985) disagrees strongly with Sharma and colleagues (1980) on the presumed lifeway at Mahadaha. The latter authors contend that all of the microlithic tools from Mahadaha were used for hunting-related purposes. However, Varma (1985:31) contends that blade tools, which comprise slightly more than one-half of the microlith inventory, could have been used for "purposes other than hunting." Microscopic examination of edge wear on the microlithic tools from Mahadaha, such as the microwear study of the tool assemblage from the Upper Palaeolithic site of Baghor III (Sinha 1989), could provide a more definitive answer regarding the use of these tools.

Sharma (1975) suggests that all Ganga Valley sites are seasonal encampments used for lithic reduction and other purposes. However, Varma (1985:31) disagrees, believing that Mahadaha, Sarai Nahar Rai and other Ganga Valley mesolithic sites were inhabited on a more regular basis, and that the residents lived a "semi-sedentary life." Nevertheless, Sharma (1975) is probably correct in his contention that seasonal migrations to the Vindhyas were undertaken by mesolithic residents of the Ganga Valley in order to access lithic sources, for hunting, and to escape seasonal flooding in the Ganga Valley.

Archaeological Evidence for Diet and Food Processing

Vegetal food resources may have been greater in the Ganga Valley than in the upland areas, because of climatic, hydrological and other factors (Sharma 1975). Presumably, the deteriorating climate in the Vindhyan Hills would have influenced wild animal herds to migrate to the Ganga Valley in search of an adequate source of browse. Sharma (1975) further contends that the original migration of humans into the Ganga

Valley occurred as a result of mesolithic hunters following these animal migrations, and because of human population increase in the Vindhyas during the early mesolithic.

Faunal remains from the Upper Palaeolithic to the neolithic periods in the Vindhyas and the Ganga Valley have been analyzed by Alur (1980) and discussed by Sharma and colleagues (1980). Partially fossilized bones belonging to a wide range of wild fauna were recovered from the lake area, the butchering area, and the cemetery/habitation area of Mahadaha. The Mahadaha fauna consist of Bos indicus (cattle), Ovidae/Capridae (sheep/goat), Cervidae (antelope and deer), Bos gaurus (bison), Hippopotamus palaeindicus (hippopotamus), Sus scrofa (swine), Equidae (horse), Carnivoridae (carnivores), Rattus rattus (rat), Chelonia (tortoise), Galliformes (chicken-like land birds), and unidentified species of fish and snails. However, wild species of sheep and goat formed the principle component of the diet, based on the greater frequency of bones attributed to these species (Alur 1980; Pal 1988; Sharma 1975; Sharma, et al. 1980). Alur (1980:226) indicates that only wild species of fauna were identified at Mahadaha, based upon identifiable wild traits such as the presence of a reduced medullary cavity in irregular and small bones, and upon the estimated body size of these animals. Also, most of the animal bones exhibit evidence of butchering and roasting, in the form of cut marks or charring, respectively (Misra and Pal 1980). In fact, the fact that most of the recovered animal bones are at least partially charred lead Misra and Pal (1980) and also Sharma (1975) to conclude that the residents of Mahadaha roasted the meat of these animals directly on coals in pit hearths. However, it is also possible that the bones were simply discarded into the hearths, after the cooked meat was consumed.

Very limited palynological analyses have been conducted on fill from Mahadaha (Alur 1980). However limited, the palynological evidence points to the presence of wild forms of grasses at Mahadaha and in the surrounding parts of the Ganga Valley (Misra and Pal 1980). Kajale (1991) reported the presence of two types of wild rice (Oryza rufipogon

Griffith; Oryza spontanea Rosc.), based on remains of the pericarp and impressions of other plant parts (glumes, caryopsis, spikelets). Also present were fruit stones of the Indian jujube (Ziyphus spp.) and charcoal from bamboo (Kajale 1991). The pollen of pine trees has also been identified from Mahadaha fill. However, Misra and Pal (1980) indicate that the pollen was not locally derived, but instead was probably transported by air or water from pine stands in the Himalayan foothills to the north. A climate more humid than at present is suggested, based on the presence of bison, elephant and hippopotamus, as well as lush growths of wild grasses (Misra and Pal 1980). In addition, the nearby mesolithic site of Damdama has yielded flotation samples of several wild plant species, many of them "camp following weeds" (Kajale 1991:169), as well as wild grasses, Chenopodium cf. album (Goosefoot), and several types of Portulaca cf. oleracea (Kajale 1991; Varma et al. 1985; Varma 1989). In general, the botanical evidence combined with the presence of groundstone artifacts, such as sandstone querns and mullers used in the preparation of plant foods, are indicative of collection and processing of the seeds of wild cereals, roots and other plants in the Gangetic mesolithic period (Misra and Pal 1980; Sharma et al. 1980; Varma 1989).

Burial Complex

Each of the Mahadaha graves has an oblong shape and is fairly shallow. Some of the graves also possessed a thin cushion of soil upon which the corpse was laid (Misra and Pal 1980). Although Mahadaha and Damdama graves share many features, the Mahadaha graves were not piled with earth (tumulus) covering as were the Damdama graves (Varma, et al. 1985). According to Varma (1985), extended and flexed burials, and fractional burial (secondary interment) practices were comon during the mesolithic period. However, at Mahadaha all of the skeletons were interred in the graves in extended supine position. Orientation of the majority of Mahadaha skeletons was west-east, with the head toward the

west, as is true of most mesolithic burial sites (Misra and Pal 1980; Pal 1985). The hands and arms were extended along the body and the skull was facing north.

A total of 17 individuals were discovered in 15 graves at Mahadaha during the 1978 excavation. As previously mentioned, additional skeletons excavated during 1979 increased the total number of individuals from the site to 35, and of these a total of 26 individuals have been described (Kennedy 1984). Two of the graves each contained two individuals, a male and female. Varma (1985) speculates that the presence of mixed-gender multiple burials at Mahadaha is indicative of the presence of small family units. A simultaneous time of death is possible for the male and female in each of the two graves, with cause of death due to trauma or to an infectious disease (Misra and Pal 1980), or perhaps to a hereditary abnormality.

Of the 26 individuals described to date, 18 are determined to be male, 6 are female, 1 is of indeterminate sex, and 2 children of inderterminate sex were recovered (Kennedy 1984; Pal 1985). All of the individuals were young adults or adults at the time of death, a phenomenon that is fairly common among prehistoric hunter-gatherer populations. Males ranged in age from 17 to 40 years, and the females exhibited an age range from young adulthood to 60 years (Kennedy 1984). However, the age at death of many individuals from Sarai Nahar Rai was slightly younger than at Mahadaha (Dutta 1973, 1984b; Varma 1985), and a much younger age range has been estimated for Vindhyan skeletal collections (Varma 1985). Varma (1985) suggests that the differences in lifespan for these relatively contemporaneous sites is indicative of a comparatively easier lifeway at Mahadaha, although sampling error cannot be discounted as a factor in the demographic relationships. With regard to burial offerings, necklaces or earrings have been recovered from three graves, and two male individuals had been interred wearing ornaments, such as bone pendants, necklaces fashioned from rings of bone or antler, and antler earrings (Misra and Pal 1980; Varma 1985, 1989). Burial offerings also consisted of bone arrowheads, animal

bones, and microliths (Misra and Pal 1980; Varma 1985). However, ornaments were not found associated with any of the graves at Sarai Nahar Rai (Misra and Pal 1980).

Osteology and Paleopathology

Recently, osteological and paleopathological analyses have been undertaken on the Mahadaha skeletal remains (Kennedy 1984; Pal 1985; Sinha 1983). The partially fossilized remains consist predominantly of limb bones, ribs, vertebrae, pelves, and phalanges. Only the skulls of seven individuals were preserved, of which three were fairly complete (Misra and Pal 1980). However, dental and/or gnathic remains of sixteen individuals were preserved (Lukacs and Hemphill 1992). Mahadaha individuals exhibit tall stature and marked cranial and postcranial robusticity, traits they share with the Sarai Nahar Rai series (Kennedy 1984). However, the Mahadaha series differs from that of Sarai Nahar Rai in that the frontal regions and the brow ridges are both somewhat reduced in the Mahadaha series. Three types of pathological conditions have been reported in three separate individuals: "osteosarcoma or chondrosarcoma of the right ilium, osteophytosis of the lumbar vertebrae accompanied by osteoarthritic lipping," and "bowing of the femoral diaphysis" (Kennedy 1984:41). In general, the residents of Mahadaha exhibited few osteological signs of disease stress and were apparently well-nourished, due to consumption of only local native and unprocessed foods (Kennedy 1984).

A detailed catalogue of the skeletal remains and description of the 15 graves excavated during the first season has been provided by Misra and Pal (1980). Skeletal remains excavated from the remaining graves have been described by Pal (1985). Kennedy's (1984) comparative analysis of the Mahadaha series included univariate and multivariate analyses of skeletal morphometrics from the Mahadaha, Sarai Nahar Rai, and other mesolithic skeletal series. Generally, the relatively contemporary populations of Mahadaha and Sarai Nahar Rai are unique among other mesolithic populations, and they

share features relating to cranial and facial size-and-shape, orbital form, stature estimates, and dental dimensions (Kennedy 1984). In addition to the shared morphometrical features between these two series, they also share discrete or nonmetrical traits of the crania and postcranial skeleton. Consequently, Kennedy concludes that the Sarai Nahar Rai and Mahadaha populations possess close genetic ties and may have been only a few generations removed from each other, as part of a regional macropopulation. In addition, the only resemblances between these two Indian populations and other mesolithic non-Indian populations correspond to "polygenic and developmental features of tall stature, skeletal robusticity, and megadonty" (Kennedy 1984:50). Sharma (1975) suggests that the similar body size of males and females at Mahadaha is indicative of non-gender specific occupations. However, ethnographic evidence from various hunter-gatherer groups indicates that, although male and female body size may be similar, gender specific task specialization is common.

A descriptive catalogue of the morphology and pathology of Mahadaha dental and gnathic remains, as well as a comparative dental morphometric analysis, have recently been provided by Lukacs and Hemphill (1992). Five individuals, from whom molar samples were obtained for the present study, are all males who were young adults at the time of death. Lukacs and Hemphill (1992) provided a qualitative assessment of the degree of attrition exhibited in maxillary and mandibular teeth of these individuals. Pastor and Johnston (1992) scored the attrition and qualitatively analyzed the microwear of molar teeth from the Mahadaha series. Results of this study were discussed previously in Chapter II.

According to Sharma (1975), the teeth of Sarai Nahar Rai individuals are very worn, a trait the author attributes to chewing bones. However, many other dietary and non-dietary factors may have influenced the observed high degree of tooth wear (Molnar 1971a; Molnar and Molnar 1990). Macroscopic examination reveals that the teeth of many of the Mahadaha individuals exhibit severe attrition (Misra and Pal 1980; Pal 1985). The

more recent assessments of tooth wear by Lukacs and Hemphill (1992) and by Pastor and Johnston (1992) confirm the earlier assessments and indicate that all tooth classes at Mahadaha were predilected for a high degree of macroscopic wear. For example, the mean Molnar score (Molnar 1971a) for M_1 of five individuals from Mahadaha is 4.20 and the mean Scott score (Scott 1979a) is 21.40 (Pastor 1990a, b; Pastor and Johnston 1992). In fact, Pastor (1990a, b) found that the macroscopic wear of the Mahadaha lower first molars was significantly greater ($p < 0.05$) than that of molars from the chalcolithic (MR2) site of Mehrgarh, Pakistan (refer to Chapters V and VI for a complete discussion of the tooth wear of the Mahadaha series, and a comparison with that of the other series).

In general, the degree of attrition on the Mahadaha lower molars is similar to other hunter-gatherer populations from North America, Europe and the Near East, in which the wear plane tilts buccally at a shallow angle, and where the occlusal surfaces of more severely worn teeth possess a partially concave to flat form (Pastor 1990a, b). Such a severe degree of tooth wear is indicative of a very coarse and abrasive diet (Lukacs and Hemphill 1992; Pastor 1990a, b; Pastor and Johnston 1992). Furthermore, the low prevalence of dental caries (1.2%) indicates that the Mahadaha diet contained very low amounts of carbohydrates, soft sticky foods, or refined sugars (Lukacs and Hemphill 1992). According to these authors, the moderate incidence of pulp exposure among Mahadaha residents may be attributable to a coarse diet, as well as to non-dietary manipulative use of the teeth (refer to Chapter II for a discussion of the causative factors for tooth wear). In addition, frequent and chronic growth disruptions were experienced by the Mahadaha population, as evidenced by the high frequency of mild enamel hypoplasias (Lukacs and Hemphill 1992).

Kennedy (1984) describes the Mahadaha dentitions as megadont, but this apparently does not correspond to standard dental indices for megadonty (Lukacs and Hemphill 1992). Nevertheless, Mahadaha tooth size is large and the total tooth crown area

is 1314 mm^2, a figure that separates Mahadaha from all other prehistoric skeletal series yet reported for the Indian subcontinent. Also, Mahadaha dentitions are unusual in that there is a "lack of reduction in distal members of a given tooth class," a characteristic which contributes to the large tooth size of the series (Lukacs and Hemphill 1992:262). With regard to dental morphology, the Mahadaha maxillary and mandibular posterior teeth are conservative, whereas the maxillary anterior teeth are "lightly but consistently sculpted" (Lukacs and Hemphill 1992:262). For example, the frequencies of expression for accessory cusps is low for molar teeth, and Carabelli's trait is completely absent from maxillary first molars. However, moderate levels of median lingual ridge development and lingual shovelling are present on maxillary central incisors, and relatively high levels exist for marginal interruption grooves.

Lukacs and Hemphill (1992) compared dental morphology trait frequencies for Mahadaha and Sarai Nahar Rai with those of other prehistoric South Asian skeletal series. Based on the Mean Measure of Divergence technique, the authors suggest that the mesolithic Ganga Valley sites are not linked genetically with geographically proximate and/or temporally distant skeletal series. Their results indicate that Mahadaha possesses closer genetic affinities with the neolithic site of Mehrgarh (MR3), Pakistan, but is relatively distant from the temporally distant late chalcolithic site of Inamgaon. The authors consider this circumstance unusual, because the latter site is closer geographically to Mahadaha than is Mehrgarh. An additional comparison of the morphological traits of teeth from the late bronze age-early iron age site of Timargarha indicates some affinities with the nearly contemporaneous site of Inamgaon, but a more distant relationship with the mesolithic series from the Ganga Valley or to the neolithic Mehrgarh series (Lukacs and Hemphill 1992). However, more similarities exist between the residents of neolithic Mehrgarh and those of late chalcolithic Inamgaon. Consequently, Lukacs and Hemphill (1992:261) speculate that "there may have been a movement of people out of the Indus

Valley drainage south and east towards the Deccan Plateau after the neolithic, but before the late chalcolithic."

Mehrgarh

Location and Chronology

Beginning in December 1974, excavations at Mehrgarh were conducted by the French Archaeological Mission to Pakistan, with the collaboration of the Department of Archaeology of Pakistan. The field director for the excavations was Jean-Francois Jarrige, currently Director of the Musee Guimet, Paris. Pascal Sellier excavated the human burials at Mehrgarh and conducted osteological analyses, which are ongoing. However, osteological analysis of the MR2 or MR3 remains are not yet completed or fully reported (Lukacs, personal communication 1992).

The site of Mehrgarh is located in the north of the Kachi plain of Baluchistan and at the foot of the Bolan Pass, an important early travel corridor between the Indus Valley to the east and the Iranian plateau to the west (Jarrige 1981, 1984; Jarrige and Meadow 1980). The Bolan River flows south from the Suleiman mountain range and cuts directly through the site (Lechevallier and Quivron 1985). At the beginning of the 20th century, severe flooding of the Bolan River caused it to change its course. Erosion of the west bank eventually exposed a section consisting of approximately ten meters of archaeological deposits. Periodic flooding occurred at the site, as evidenced by the alluvial deposits separating the different archaeological sequences (Costantini 1984). In addition to the cut-bank, the site originally appeared as a small mound on a flat alluvial plain, covering an area of slightly more than 200 hectares (Jarrige 1981). The relatively flat Kachi plain is a large expanse of alluvial outwash that stretches to the Indus River, 200 kilometers to the southeast (Jarrige and Meadow 1980). Also, the presently occupied village of Mehrgarh is located nearby (Figure 3.1).

The site of Mehrgarh is unique in South Asia for its levels of continuous occupation spanning several millennia, from the seventh to the end of the third millennium B.C. (Lechevallier 1984; Meadow 1984). Evidence from other Baluchistani sites indicates that prehistoric settlement continued to the middle of the first millenniun B.C. (Jarrige 1985). Mehrgarh represents the earliest center for plant cultivation and animal domestication within the greater Indus Valley. It was also a center for technological innovation, including the early use of the potter's wheel to mass produce fine ware. The bow drill and green jasper drill bits were also used during later phases to fashion jewelry from semi-precious stones of lapis lazuli, turquoise and carnelian.

During the 1970's, a diffusionist model was popular for conceptualizing the settlement of Mehrgarh (Jarrige 1981:93). Many of the early archaeologists to work on prehistoric settlement patterns in Baluchistan (e.g., Fairservis 1956, after Jarrige 1981), and during the initial excavations at Mehrgarh, considered the area to have represented a 'cultural backwater.' According to Jarrige (1981), many of the technological innovations observed at Mehrgarh, such as elaborate architectural styles, polychrome ceramic styles, and work with semi-precious stones suggested that the area had been influenced heavily by cultural influences from and possibly long distance trade with eastern Iran (Tepe Yahya and Shahr-i Sokhta), Turkmenia, and Afghanistan (Mundigak). For example, the initial finds of 'Amri' or 'Kechi Beg' styles of polychrome ceramics suggested that a chalcolithic lifeway was introduced to Baluchistan from the Near East at the end of the fifth millennium B.C. An apparent change to the 'Quetta' style of pottery at the end of the fourth millennium was taken as evidence for the spread to Mehrgarh of a new and more complex cultural assemblage from South Turkmenia (Jarrige 1981). In addition to the change in ceramic styles, the stamp seals, human figurines, elaborate architecture, and semi-precious stones found during this time in Baluchistan were taken as evidence for the spread of

cultural elements through such sites as Mundigak (Period III), which was contemporary to the initial phase at Shahr-i Sokhta in the Helmand delta (Jarrige 1981).

However, more recent excavations at Mehrgarh have revealed the local technological innovation and cultural continuity that existed at Mehrgarh from the neolithic onward. This alternative concept for the internal development of Mehrgarh is illustrated by the following passage from Jarrige (1981:96): "If a way of life spread to Baluchistan from the Near East it was not the chalcolithic one arriving about 4000 B.C. but a neolithic one coming some 3 or 4 millennia earlier. From at least the beginning of the 6th millennium the Mehrgarh area must be considered a center of innovation where one can observe successive stages of increase in farming and craft activities resulting from internal factors of change reinforced in the 4th and early 3rd millennia by contacts and trade with other regions of Southwest Asia." In considering the architectural styles at Mehrgarh, of which some buildings seem to represent grain storage facilities, Jarrige (1981:105) states that "it is possible that the granary of Harappa is to be linked to a continuous tradition going back to the neolithic in Baluchistan." It seems evident that the site of Mehrgarh was continuously inhabited beginning at an early date, and extending to at least the Harappan period several millennia later. During the neolithic and chalcolithic periods, Mehrgarh functioned as a center of technological innovation with respect to the mass-production of ceramic vessels and jewelry. During the seventh through the fifth millennia, long distance trade existed between Mehrgarh and communities in the western uplands, from whom raw materials could be obtained. Rather than diffusion of technology to Mehrgarh from these uplands areas, the pattern may have instead been reversed, since the exchange of manufactured goods from Mehrgarh with the upland communities may have influenced these outlying populations to adopt similar styles of pottery and ornamentation. Although the archaeological evidence points to cultural continuity with outside influence between all periods at Mehrgarh, recent dental morphometric evidence does not support this viewpoint

(Lukacs and Hemphill 1991). In this study, multivariate analyses of discrete dental traits indicated instead that close biological affinities do not exist between the MR3 and the MR2 populations. For example, MR2 exhibited closer biological affinity to later bronze and iron age Pakistani skeletal series from Timargarha than to MR3. The analysis indicated that the MR3 skeletal series possesses closest affinity to chalcolithic Inamgaon, an early farming village in western peninsular India. Lukacs and Hemphill (1991:116) conclude that "The people of MR2 do not appear to be the direct and exclusive descendants of the neolithic inhabitants of Mehrgarh (Period I, MR3), but represent a genetic amalgam of the regional populations of Baluchistan."

The currently accepted cultural chronology for Mehrgarh is based upon radiocarbon dates and pottery styles related to other sites. However, the datation determined from the radiocarbon dates is somewhat suspect, especially for the lower levels, because of possible contamination of charcoal deposits in deep strata by fossilized plant roots. Dates as old as 32,650 B.P. have also been obtained from mid-levels at MR3, an indication that some of the charcoal samples had been contaminated by geologically-derived carbon material (Jarrige 1984; Lechevallier and Quivron 1981).

The following discussion of the cultural chronology for Mehrgarh focuses on Periods I and III, from which dental samples were obtained for analysis. The late chalcolithic phase at Mehrgarh (MR1, Periods IV-VII) contained few human burials (Lukacs et al., 1985), and therefore was not used as a sample source for the dissertation research presented herein. The neolithic period at Mehrgarh (MR3, Periods IA and IB) dates to between the seventh and sixth millennia B.C. (Lechavallier 1984), based partially upon similarities of the Period I flint assemblage to those from early prehistoric sites from western Iran and Turkmenia. For example, many concave-backed flint trapezes have been recovered from Period I at the site of Kile Gul Mohammad, as well as from Period I of Mehrgarh (Lechevallier 1984). Kile Gul Mohammad, the early periods of which are also

aceramic, is located in the Quetta Valley of Baluchistan to the northwest of Mehrgarh, and was found by W.A. Fairservis in 1950 (Lechevallier and Quivron 1981). However, Jacobson (1979) has expressed some reservations about the age estimates for cultural deposits at Kile Gul Mohammad, because the dating was based on uncorrected radiocarbon readings. Although Lechavallier and Quivron (1985) suggest that Period IA extends as far back as the eighth millennium, such an ancient date must be accepted cautiously because it is based on preliminary sedimentological evidence.

The ceramic neolithic and early chalcolithic site of MR 4 (Period II) dates to the fifth millennium B.C. No cemetery or isolated human skeletal remains have been discovered in this area of the site, which surrounds the site of MR3 (Lechevallier, 1984). The earlier occupation in Period II is represented by a shallow archaeological stratum containing "crude, straw-tempered and ill-fired pottery" (Lechevallier, 1984). According to Jarrige (1981), the later part of this period (IIB and IIC) is represented by styles of painted pottery that occur elsewhere at other upland valley sites of the same time period. The Bolan Pass and other mountain passes linked these upland sites with the Kachi plain, and the presence of similar pottery styles at remote locations "reflects the beginning of an integrated system of exploiting upland and lowland resources" (Jarrige 1981:107).

The late chalcolithic site of MR2 (Period III) has been dated to the beginning of the fourth millennium B.C., although only a single radiocarbon date has been obtained from Period III levels (Jarrige 1984). The aforementioned problems with radiocarbon and sedimentological datation also hold for Period III. With regard to MR2 pottery styles, finely made ceramic wheel-thrown vessels replaced the hand-made pottery that is very commonly found at MR4 (Jarrige 1981). Further evidence for an early fourth millennium B.C. time frame for Period III comes from comparisons of ceramic sequences with other prehistoric sites to the west and north. Consequently, two phases of occupation have been identified. The earliest phase is typified by the presence of buff or red wheel-thrown ware

with more complex geometric motifs than in Period II, a style characteristic of the second phase at Kili Gul Mohammad. However, from later cultural levels of Period III are found fine ceramic ware with complex animate motifs, consisting of rows of caprids and birds. This style is characteristic of Togau A and KGM III ceramic ware, which are typical of the first half of the fourth millennium B.C. at Kili Gul Mohammad III.

Neolithic Mehrgarh (MR3, Periods IA and IB)

Archaeology

Several large excavation units and deep trenches (sondages) were opened in the area of MR3, which exposed the archaeological deposits by controlled level. Period I was originally divided into six subdivisions, by archaeological strata and by location, with three phases (A-C) represented. These subdivisions were encompassed by four stratigraphic units or building levels (I 4 - I 1), but the length of time represented by each of these units is still not known (Lechevallier 1984; Meadow 1981:160). More recently, Lechevallier and Quivron (1985) have reevaluated the occupational sequences that were originally outlined for MR3, based on evidence from ongoing excavation and trenching. The authors suggest that a discontinuity exists in occupation at MR3, based on evidence from stratigraphically different pottery sequences, architectural styles, and on the presence of both wild and domesticated animals. Consequently, they have combined the original stratigraphic levels into two phases: Period IA, and Period IB.

Generally, Period I represents a pre-ceramic culture that comprised a very long-lasting occupation. Although technically pre-ceramic (aceramic), this period contains evidence of bitumen-lined baskets, which may have been the earliest precursor to pottery (Allchin and Allchin 1982). Also, a few coarse chaff-tempered pottery sherds have been found in some buildings belonging to Period IB, but these levels are apparently older and discontinuous from pottery-containing Period IIA buildings (Lechevallier and Quivron

1985). In both Periods I and II, a microlithic blade industry is represented, with the tool assemblage consisting primarily of geometric microliths fashioned from flint (Lechevallier 1984). According to Lechevallier (1984), the fact that these microliths possess varied and unstandardized morphology is indicative of a possible epipalaeolithic connection. The functional variability of the artifacts may also indicate that some craft specialization had been practiced during Periods I and II. In addition, parallels in the flint assemblage exist between Period I at MR3 and with "early village sites of western Iran and early neolithic sites of Turkmenia, where numbers of the same concave-backed trapezes are found" (Lechevallier (1984:50). However, the Bolan River apparently functioned as a local source for the flint, in the form of water worn pebbles and cobbles. The proportion of thin bladelets to blades was greater during Period I than during later periods, and fewer of these bladelets exhibit phytolith polishing. Consequently, Lechevallier (1984) suggests that many of the flint microliths were set in bitumen and used as transverse arrowheads or as serial barbs of spear heads. These weapons were likely used for hunting and defensive purposes. The gloss observed on the working edges of some of the lunate-shaped microliths and on a small proportion of unretouched blades from Period I is indicative of their use as cutting elements of sickles. In fact, two large sickle blades consisting of a row of bladelets set in bitumen were discovered at MR3. The sickles were undoubtably used to harvest grains from wild and/or domesticated plants (see succeeding section for further discussion of plant cultivation).

The lack of finely-worked burins at MR3 is in strong contrast to their abundance at MR2 (Lechevallier and Quivron 1981), an indication that cutting and sawing activities were commonly practiced at the latter site. However, the fact that burins are normally associated with bone working does not correspond directly with their proportions from each site, because a greater abundance of bone tools were found in the first two periods than in Period III (Lechevallier 1984). Stone and shell bead production were also practiced during

Period I, as witnessed by the elaborate adornments of necklaces, bracelets and anklets found in some of the burials. Both rough stone axes and adzes, and well-polished stone axes were discovered, the latter of which are in context with graves. Lechavallier (1984) suggests that these heavy tools were used to cut and process timbers for the roofs of the mud brick houses, and also possibly as agricultural implements. Allchin and Allchin (1982) believe that the large number of ground stone axes found at MR3 indicates that the technique of pecking and grinding stone was an early neolithic innovation within the greater Indus Valley.

Architectural Styles

MR3 architectural styles vary depending on stratigraphic level, as determined primarily from two soundings. The MR3-S sounding produced eight main building levels and 28 graves, whereas the MR3-T sounding produced seven building levels and eleven burials. The many structures found in both Periods IA and IB consisted of four and six room rectangular buildings, the walls of which were oriented in north-south and east-west directions. These were constructed of unfired cigar-shaped mud bricks. The typical floor plan consists of small rooms with no windows, although a low door is occasionally present along one wall. These are considered dwellings because of the presence of fireplaces with burnt pebbles, mortars, pestles, and flint and bone tools in some of the buildings. Also at the periphery of the Period IB level were compartmented buildings and large mud-brick retaining walls. These compartmented structures were apparently the first to have been discovered at Mehrgarh. Lechevallier and Quivron (1981) suggest that only one in four structures of the Period Ia structures were used for habitation purposes, while the majority were probably used for storage or as holding pens for animals. Meadow (1984a) suggests that this trend continued through the mid-fourth millennium B.C. In general, simple multi-room structures are predominant during Period IA, a feature which Lechavallier and

Quivron (1985) consider indicative of well developed village life involving agriculture, herding and also hunting. A similar cultural tradition is continued during Period IB, but also present are elaborate tombs in association with a mud brick wall, and compartmented structures of mud brick that were likely used as agricultural storage facilities (Lechevallier and Quivron 1981, 1985).

Archaeological Evidence for Diet and Food Processing

Many grinding stones are present at MR3 (Lechevallier and Quivron 1981), often on the floors of structures that may have functioned as dwellings or as domestic activity areas. Such contextual evidence is indicative of the use of these grinding stones for processing vegetable matter for human consumption. Grinding stones were also discovered in association with burials at MR3. However, the red ochre found on the ground stone artifacts may indicate their use for crushing and pulverizing ochre for use in funerary rituals, rather than for grinding and processing grains or other material. These same authors indicate that many individual bones from the MR3 graves were stained with red ochre. Cakes of ochre were also found in some of the graves, probably as a form of ritual offering.

Only limited pollen studies have been done for Holocene deposits in Pakistan, including those at Mehrgarh (Meadow 1989). Analysis and description of botanical remains from Periods I through III at Mehrgarh are available in two reports (Costantini 1984; Costantini and Costantini Biasini 1985), while discussion of the development of agriculture during the Harappan period in Pakistan is provided in a later paper (Costantini 1990). Additional discussion and insights regarding the development and cultivation of agricultural crops at Mehrgarh are provided by Meadow (e.g., Meadow 1984a, 1986, 1989). Much of the evidence for plant cultivation and use during Period I is derived from straw and grain impressions in the ubiquitous mud bricks used for building construction.

Costantini (1984) suggests that the straw used in the manufacture of these bricks was the plant refuse left from the threshing of grains cultivated for consumption by the human populace or by domestic livestock. Some charred plant remains were also found in conjunction with fireplaces, floors, and storerooms.

Naked six-row barley (Hordeum vulgare var nudum) is by far the most prevalent of all charred seeds and plant impressions in the botanical assemblages of Period I (Meadow 1984a). The strong prevalence of naked barley over hulled barley is an indication that the plants being cultivated during Period I were not yet completely domesticated (Costantini 1984). Other floral remains and impressions found in much smaller amounts include: H. vulgare (hulled six-row barley), H. spontaneum and H. distichum (two-row barley), Triticum monococcum (einkorn), T. dicoccum (emmer wheat), and T. durum/aestivum (durum/bread wheat). The proportion of naked to hulled barleys is constant through Period VI, with the hulled varieties increasing modestly only in Period VII. Together with the slowly decreasing frequency of naked barley is an increase in frequency of naked wheat with later periods (Costantini 1984). According to Meadow (1984a), the presence of domestic wheats in the earliest aceramic levels at Mehrgarh is intriguing, because the previous known distribution of wild einkorn and emmer wheat was far to the west in early eighth millennium B.C. sites from the Near East. Apparently, bread wheat may have originated in the Near East from "a series of mutations and crosses between emmer and the goats-face grass Aegilops squarrosa", the latter of which is distributed across portions of the Iranian plateau, Afghanistan, southern Soviet Central Asia, and western Pakistan (Meadow (1984a:315). Meadow (1984a) believes that the free-threshing wheat T. aestivum may have originated by at least the beginning of the seventh millennium B.C. in Pakistan, due to a naturally-occurring cross between emmer wheat and goats-face grass. If this scenario is accurate, then "the presence of fully developed durum/bread wheat" in the earliest aceramic levels at Mehrgarh is an indication "that agriculture had been practiced for

some time in the region" (Meadow 1984a:316). Costantini (1984:31) adds that the hulled wheat of Period I "had already undergone an intensive process of cultivation and domestication." However, it should be noted that such a theory presumes that durum/bread wheat was domesticated locally at Mehrgarh over two to three millennia, rather than being imported later on as seed for use in sowing fields. In addition, the low proportions of both naked and hulled wheats in Period I, when compared to naked barley, suggests that this grain comprised very little if any of the aceramic neolithic Mehrgarh diet.

Two large date stones (Phoenix dactylifera) have also been found during both neolithic Periods I and II, and their large size compared to varieties from third millennium B.C. sites from the Gulf may indicate that dates were cultivated during the early settlement of Baluchistan (Costantini 1984; Meadow 1989). The only other non-cereal plant identified from Period I, as well as from all other periods, is the indiginous jujube (Zizyphus sp.). Cotton seeds (Gossypium sp.) have also been found near a compartmented building from Period II, which places the date for the appearance of this taxa much earlier than previously recorded from any other prehistoric site. Meadow (1984a) emphasizes that cereal grain domestication at Mehrgarh and other prehistoric sites in the Near East preceded the domestication of wild mammals. The author also suggests that the sudden occurrence of bones of the wild ass in the middle and later MR3 assemblages may be evidence of, and associated with, an increase in field crop agriculture (Meadow 1981). The review article by Meadow (1984a) provides an in depth discussion of the processes of domestication of wild taxa of both animals and plants, as perceived from the progressive changes in proportions of wild and domestic fauna and flora. The domestication process is summarized in the following passage:

> Animal domestication, in the case of food species, can be defined as a selective diachronic process of change in human-animal relationships involving, at the very least, a shift of focus from the dead to the living animal and, more particularly, from obtaining and distributing the products of the dead animal to securing and selectively maintaining the most

> important product of the living animal -- its progeny. This process, while differing in particulars from species to species, manifests itself in structural transformations in the socio-economic dimensions of the human societies which interact with the living animals, and in changes in the behavior and sometimes in the morphology and physiology of the animals undergoing domestication (Meadow 1984a:310).

Analyses of mammalian faunal remains from the neolithic levels at Mehrgarh have been elucidated in a series of reports by Meadow (1981:155, 1984a, 1984b, 1986, 1989:65). Meadow (1986) cautions that species counts at Mehrgarh are purely summary and not indicative of the presence of a particular animal at any one level, because of the small sample of identifiable specimens. Rather, he emphasizes that the overall trend for change in body size and taxa representation between different levels and strata can provide insight regarding hunting, herding, domestication, or a combination of all three over time at Mehrgarh. Apparently, the domestication of formerly wild stock results in a diminution of body size, beginning as early as the second generation. Increases in body size of domestic bovids occurs only when selective breeding is practiced, a practice for which there is no evidence during the neolithic and possibly through the chalcolithic periods at Mehrgarh. However, selective breeding for larger body size apparently was practiced at Mehrgarh during the Harappan period, several millennia later. Wild ungulates and other large game, many of which are presently extinct, formed a dietary staple during the early aceramic neolithic (Period IA) at Mehrgarh. Gazelle, blackbuck, onager, and pig continued to provide a dietary supplement during Period IB as well as later phases, as indicated by the continued presence of bones of these animals in small quantities throughout the later levels. Apparently, the collecting of fish, birds or turtles was extremely minimal during any phase at Mehrgarh (Meadow 1986). According to Meadow (1981, 1984a) the wild ungulates identified from the earliest levels of Period I include, in approximate order of abundance: Gazella dorcas (chinkara or gazelle), Ovis ?orientalis (wild sheep), Capra ?aegagrus (wild goat), Cervus duvauceli (barasingha or swamp deer), Boselaphus tragocamelus (nilgai or

blue bull), Bos ?namadicus (wild Indian cattle). Other wild ungulates represented by fewer specimens include: Bubalus bubalis (water buffalo), Axis axis (chital or spotted deer), Equus hemionus (onager), Antilope cervicapra (blackbuck), Sus scrofa (wild boar), and a single specimen belonging to Elephas maximus (elephant). Wild carnivores represented in Period I include: Canis aureus L. (jackal), Vulpes sp. (fox), and ?Felis caracal (caracal). According to Meadow (1981), specific taxa of domestic mammals represented at Mehrgarh in the later parts of Period I include: ? Canis familiaris L. (dog); and three species of bovid: Bos ?indicus L. (zebu cattle), Capra hircus L. (domestic goat), and Ovis aries L. (domestic sheep).

Meadow (1981, 1984b, 1986) indicates that the number of bones of sheep, goat, gazelle, and other medium-sized mammals continuously decreases, while those of cattle, swamp deer, nilgai, and other large mammals show a gradual increase throughout Period I. However, more recent analyses of faunal material by Meadow (1984a; 1989) indicate that three "prodomestic" genera (sheep, goats and cattle) comprise the majority of fauna present by the end of Period I. This progressive transition resulting in an increase in frequency of domesticated forms, especially Bos, and a decrease in frequency of wild forms suggests that the early neolithic people practiced hunting, while late neolithic occupants of Mehrgarh were predominantly but not exclusively herders (Meadow 1984a). By late Period I, both animal husbandry and cultivation of cereal grains (barley) provided most of the nutritional input. Apparently, domestication of bovid species results in a marked reduction in the dimensions of bones, such as the phalanges and also the larger limb bones. According to Meadow (1984a, 1984b), the decreasing size of the Zebu cattle (Bos indicus) bones during progressive stages of the aceramic neolithic is indicative of domestication of this species. Furthermore, the author believes that because of the larger body size of even the domestic cattle at Mehrgarh, when compared to that of the medium-sized mammals, they represent a larger contribution to the diet. He suggests that this is true even for the early stages of

Period I, although the relative proportions of cattle bones are small compared to those of goat, sheep and other medium-sized mammals. Arguments Meadow has presented in favor of this hypothesis include the fact that goats and sheep possess shorter generation times than the much larger cattle, allowing a herder to build up herd size more quickly and to slaughter more animals. But the larger carcass resulting from the slaughter of a cow or bull would contribute much more meat to the Mehrgarh diet. However, in the absence of methods for preservation the meat would need to be distributed to several individuals or families, perhaps along kinship lines. Additional evidence for goats having been herded during the very earliest of the neolithic period includes: the small size of the goat bones, which can be taken as an indication that domestication has occurred; and the presence of five articulated caprine skeletons, in context with two human burials from the earliest levels of Period I (Meadow 1984a). Meadow (1984a:327) summarizes the analyses of neolithic Mehrgarh fauna as follows:

> (1) goats were kept from the time of the earliest occupation of the site; (2) cattle and sheep were domesticated from local wild stock during the course of the aceramic neolithic; (3) size diminution in goats and cattle was complete by the end of Period I (5000 bc at the latest), while size change in sheep continued through the course of Period II; (4) the contribution of domestic or "prodomestic" stock to the faunal assemblages surpassed that of other animals early in the aceramic, but not in the earliest levels; and (5) the development of animal keeping by the ancient inhabitants of Mehrgarh took place in the context of cereal crop cultivation, the building of substantial mud-brick structures, and the existence of social differentiation and long distance exchange networks as attested by the presence of marine shells, lapis lazuli, and turquoise in some of even the earliest graves.

Burial Complex

Some human burials at Mehrgarh show organized interment, indicating existence of elaborate funerary rites (Lechevallier and Quivron 1981, 1985). For example, tomb 84-12 in the MR3-S sounding contained a single skeleton of an elderly woman. Her skeleton was covered with red ochre and adorned with a belt and necklace of shell and stone beads, a

weaved head-dress made from dentalium beads, and a mother-of-pearl pendant. Excavation and trenching indicated that three areas within the boundaries of MR3 possessed skeletal remains. Lechevallier and Quivron (1981) refer to these as the eastern burial ground, western burial ground, and the sondage burials. According to these investigators, Mehrgarh is unique among other neolithic villages for the presence of true cemeteries in lieu of interment beneath the floor level of a dwelling. The skeletons of all of the individuals buried at MR3 were in a flexed position (arms and legs tightly flexed), with the heads often oriented toward the south. Although some reassessment of the site stratigraphy and chronological sequences was reported in a later report by Lechevallier and Quivron (1985), most of the descriptions of the graves, the skeletal remains, and the burial offerings is contained in their earlier (1981) report. Within the burials of trench MR3T, the orientations of the eight (7 adults and 1 infant) skeletons varied from being positioned on the right side with a north-south orientation, to a position in which the skeleton is also flexed on the right side but with an east-west orientation. However, the predominant orientation of skeletons at neolithic Mehrgarh is a flexed position on the left side.

Burial offerings found in graves of the eastern burial ground include: impressions of several asphalt-coated twined baskets, a necklace of turquoise and steatite beads, a stone and shell bracelet, a stone chisel, and an impression of a textile (Lechavallier and Quivron 1981). The basketry impressions and isolated animal bones found in some of the graves provides evidence, according to Lechevallier and Quivron (1985), for ritual offerings of vegetal and animal food. These graves contained skeletons of eight individuals, including children and infants. The skeletons were interred in a flexed position, with the hands placed near the abdomen or in front of the head. Twenty-four individuals, the majority of whom were adults, were interred in twenty-one tombs at the western cemetery. Each skeleton was flexed and positoned on the left side, with an east-west orientation. The hands were usually placed anteriorly and the skull was oriented toward the east. Some of

the other burials in the western portion of the site contained secondary burials, multiple individuals, and disarticulated skeletons. The western burial ground contained such grave offerings as a lump of red ochre, a flint core, a stone cup and stone axe, a mother of pearl pendant and turquoise beads, various types of stone and shell beads, and a single cylindrical copper bead. With respect to architectural styles, the eastern burial ground possessed mud brick enclosures above ground, while the western burial grounds possessed mud brick structures that were mostly below ground level. In some of the graves, the skeleton was found lying adjacent to a low brick wall. Apparently, this style of interment is similar to that occasionally practiced at Shahr-i Sokhta, in Iranian Seistan (Lechevallier and Quivron 1981). Burials exposed by the trench contained skeletons in flexed positions with variable orientations. Structures or pits were not associated with any of these burials, although mud brick walls were found on the same levels. In contrast to the two surface cemeteries, the sondage burials consisted of burials and buildings on the same archaeological levels, but the the burials themselves are not contained within the structures. Funerary goods of the sondage burials are mostly of bone and shell, whereas turquoise and other semi-precious stones are not represented, in contrast to the eastern and western burial grounds (Lechevallier and Quivron 1981). Two flexed adult skeletons in the deepest graves of Period Ia were interred with a rich set of burial offerings, including five goat kids. Lechevallier and Quivron (1985) consider the latter as possible evidence for animal domestication, social stratification, or religious practice during neolithic times at Mehrgarh. But with such little evidence, each alternative must be considered speculative and at least as likely.

Osteology

Because the osteological analysis of the MR3 skeletal remains by Pascal Sellier is ongoing, a complete review of the osteology and paleopathology of the Period I population

is not presently possible. In addition, preservation of the skeletal remains at the cemeteries of both MR3 and MR2 is very poor, having been altered by post-mortem diagenetic processes of pressure and/or salinization. The resulting warpage, breakage, and disintegration of the skeletal remains precludes the use of craniometric and other standard osteometric assessments. However, in many cases the dentition has been preserved well enough to allow measurement, and analysis of discrete morphological traits (Lukacs and Hemphill 1991). Discussion of the physical anthropology of the occupants at MR3 is limited to a brief review of the dental metrics and morphology, which have been reported by Lukacs (1982, 1985b, 1988, 1989) and by Lukacs and Hemphill (1991). The latter paper presents a comprehensive and up-to-date dental morphometric analysis of both the MR3 and MR2 populations and a comparison with other prehistoric South Asian skeletal series. Results presented by Lukacs and Hemphill (1991) will be summarized in the subsequent section devoted to the chalcolithic Mehrgarh population. The dental pathology of neolithic Mehrgarh has been reported by Lukacs (1985b) and by Lukacs and colleagues (1985). However, neither the macroscopic nor the microscopic dental wear of this skeletal series has been previously assessed.

A total of 93 individuals were unearthed from the three burial sites in the aceramic neolithic levels of Mehrgarh. The transitional level (MR3/4) between the aceramic and ceramic neolithic produced another six individuals. According to Lukacs (1989:77), 41 of the specimens he analyzed were derived from the "upper graveyard" (level IB), 22 specimens were derived from contemporaneous burials adjacent to this graveyard, and an additional 27 individuals came from horizons below and adjacent to the "upper graveyard" (MR3F, MR3T, MR3S). A catalogue of many of the dental and gnathic remains from MR3 has been compiled by Lukacs (unpub. field notes) from various sources. Children and adults are represented in the MR3 skeletal sample, although little information is available for the ranges of age at death or sex of the individuals, because of the incomplete

preservation of the remains (Lukacs 1985b). Most of the remains examined by Lukacs consisted of skulls and mandibles, but isolated teeth were often encountered. Also, some of the remains consisted of plaster-encased skulls, precluding examination. Provenience and other information for individuals from which samples were utilized are presented in Table 3.1. Severe attrition of many teeth reduced the originally large sample of skeletal material from MR3 that could be utilized in dental morphometric comparisons. Also, alveolar pathologies have not been assessed, because of the many isolated or poorly preserved jaws (Lukacs 1985b).

Dental Morphometrics and Pathology

The dental morphometrics and pathology of the MR3 skeletal series have been analyzed and discussed in a series of reports (Lukacs 1982a, 1983b, 1985b, 1988, 1989a; Lukacs and Hemphill 1991) Generally, neolithic Mehrgarh teeth are morphologically complex and relatively large. In fact, Lukacs (1983b) concluded that megadonty is predominant in the neolithic Mehrgarh population, based on the comparison of tooth sizes between contemporary and later prehistoric cultures. In general, the dental pathology profile of neolithic Mehrgarh people includes a low prevalence of dental caries and ante-mortem tooth loss, some dental fluorosis, and a high prevalence of gross enamel hypoplasia and dental calculus (Lukacs 1983b, 1985b; Lukacs and Hemphill 1991; Lukacs and Minderman 1992; Lukacs et al. 1985). Calculus formation is often attributed to a high consumption of processed grains and other sticky foods with a high carbohydrate content, and the high incidence of dental calculus in the MR3 population may be attributable to the consumption of wild and domestic grains. However, the mixed diet at neolithic Mehrgarh is in strong contrast with that of bronze age Harappa, where the incidence of dental calculus is also high. In the absence of additional dietary evidence, dental calculus formation at MR3 remains an anomaly (Lukacs, personal communication 1993). Dental fluorosis

occurs at a fairly high frequency among individuals from neolithic Mehrgarh (Lukacs 1985b; Lukacs et al. 1985). The fluorosis is elicited in four sets of pathological symptoms in the enamel of permanent teeth: "opaque 'milky-white' patches, yellow-brown stains of varying extent and darkness, discrete and confluent pitting, and a broad flat basin replacing the normal groove pattern" (Lukacs et al. 1985:187). Most of the dental arcade was predilected, but molars and premolars were the most frequent sites of severest pitting and staining. Children from neolithic Mehrgarh did not exhibit mottled enamel in their permanent upper incisors, while modern children from the villages of Mehrgarh and Mithri commonly exhibit this pathology. In addition, dental fluorosis was not observed in the deciduous teeth from either Mehrgarh Period I or Period III (Lukacs et al. 1985). The MR3 permanent dental sample also exhibits a higher incidence of fluorosis than the chalcolithic MR2 population. However, the younger age class of the MR2 population may have ameliorated the expression of dental fluorosis simply because of the shorter period of consumption of fluoridated water (Lukacs et al. 1985; Lukacs 1985b). Based on the presence of naturally high concentrations of fluoride in water of the nearby Bolan River and other surface sources, as well as from ground water, Lukacs and colleagues (1985) suggest that the prehistoric populations of Mehrgarh were ingesting large amounts of fluoride in their drinking water. This could account for the dental fluorosis at MR3, but complicating factors also need to be considered. For example, neolithic occupants of Mehrgarh may have been acclimatized to the extreme heat during the summer (Meadow 1984a), which would have lowered their rate of sweat production through such cultural factors as wearing loose clothing, and decreased their rate of water consumption compared to a non-acclimatized population (Frisancho 1981). Consequently, water consumption may not have been increased above normal levels as suggested by Lukacs and colleagues (1985). However, seasonal migration to the mountains was probably a common practice among the neolithic herders of Mehrgarh (Meadow 1984a), and the highland water sources may have

also been contaminated by high fluoride concentrations. Therefore, the year-round consumption of fluoride-contaminated water by the Period I Mehrgarh population may indeed have contributed to the fluorosis reported by Lukacs and colleagues (1985).

The dental fluorosis present among the MR3 population is important when considering the large size of Mehrgarh teeth. For example, the Summed Molar Crown Area (SMCA) of 17 specimens from MR3 is 680.75 mm^2 (Lukacs 1982a). This figure is nearly identical to the SMCA for occupants of the southwestern Asian site of Jarmo. Late neolithic samples from the peninsular India sites of Piklihal (1900 B.C.) and Tekkalakota (1400B.C.) possess smaller molar teeth (Lukacs 1982a). Based on an hypothesis postulated by Brace and Nagai (1982), Lukacs (1985b) suggested that a significant difference exists in the Total Crown Area (TCA) of neolithic Mehrgarh teeth when compared with other prehistoric South Asian populations, such as Timargarha and Sarai Khola. However, Lukacs (1985b) believes that the neolithic Mehrgarh population would have exhibited even more exaggerated megadonty in the absence of fluorosis. In other words, the MR3 population had the potential for larger teeth in the absence of the mitigating effect of fluorine in the water supply. Lukacs (1985b) suggests that the Probable Mutation Effect model espoused by Brace (1967) holds for reduction in tooth crown size among these prehistoric populations. Inherent to this model is the notion that changes in diet, subsistence and technology exerted a selective effect on hominid dentitions. Consequently, prehistoric populations which are more complex technologically will possess smaller TCA's. Conversely, those populations that practice incipient agriculturalism, along with hunting and gathering, will exhibit larger TCA's. This is evident for the neolithic Mehrgarh population and other South Asian prehistoric populations, such as the Jorwe peoples of Inamgaon (Lukacs 1985a). A similar phenomenon has been shown for mesolithic Nubian populations (Calcagno 1986).

Both the deciduous and permanent MR3 dentition are morphologically complex. Dental traits exhibited at a higher frequency by the deciduous teeth than by the permanent teeth include: Carabelli's trait, tuberculum dentale (= median lingual ridge) of the canine, protostylid, C-6 and other accessory cusps of the lower molar. Other traits, such as C-7 and shovel-shaped incisors, were observed at a lower frequency in the the deciduous than in the permanent teeth. Also, the mandibular teeth are less morphologically complex than the maxillary teeth (Lukacs 1989a). A summary of neolithic Mehrgarh dental morphology (Lukacs 1989a:85) follows:

> Permanent teeth:
> Maxillary anterior teeth are highly sculpted, i.e., exhibit high frequencies of shovelling, lingual tubercles, lingual ridges and pits and marginal grooves.
> Maxillary molar teeth have a low incidence of Carabelli's trait and the hypocone exhibits little reduction and is rarely absent.
> Mandibular molar teeth are conservative morphologically and accessory cusps occur in moderate to low frequencies.
> Deciduous teeth:
> Maxillary anterior teeth are frequently but weakly shovelled, and canines often display tuberculum dentale.
> Maxillary molar teeth exhibit fully developed hypocones and Carabelli's trait, though common, is weakly expressed.
> Mandibular molar teeth are morphologically complex and accessory cusps are common.

Lukacs (1983b, 1989a) also compared the neolithic morphological complex with the dental morphology previously recorded for three other prehistoric South Asian skeletal series: the chalcolithic site of Inamgaon, located in western Maharashtra; and the bronze age-iron age sites of Sarai Khola and Timargarha, located in northern Baluchistan. Nevertheless, his comparison revealed that the morphology of Mehrgarh maxillary molar teeth contrasts with that of the other populations, in that the former retain large-sized hypocones and exhibit a lower frequency of Carabelli's trait. The high incidence of accessory cusps wrinkles and stylids on MR3 mandibular molar teeth also contrasts with the frequencies observed for the other prehistoric South Asian populations. While incisor and canine teeth from Timargarha, Inamgaon and Mehrgarh share some traits, the

Mehrgarh anterior teeth exhibit a higher frequency of shovelling, and canine tubercles are also more common. Generally, Inamgaon and Timargarh are intermediate with regard to dental morphology, while Mehrgarh teeth are the most complex morphologically , and Sarai Khola exhibits the most simplified dental morphology (Lukacs 1989a). Based on this evidence, the author concludes that the Sarai Khola population is genetically distinct and not derived from the neolithic Mehrgarh population. When contrasted with the neolithic-epipaleolithic Natufians of the Near East, neolithic Mehrgarh anterior teeth share several traits, but exhibit them at a higher frequency. The incisor and canine shovelling is very common at Mehrgarh, but extremely rare among Natufians. In addition, molar morphology among the MR3 population contrasts with that of Natufians. For example, Carabelli's trait is much more common among the Natufian population. According to Lukacs (1989a:86), these contrasting dental patterns "suggest a distant genetic relationship between the Natufian and neolithic Mehrgarh samples." Apparently, the neolithic Mehrgarh dental complex contrasts strongly with the European dental complex reported for modern north Indian populations of northern India (Zubov 1980, after Lukacs 1989a). Instead, frequencies for such dental traits as Carabelli's trait, three-rooted lower first molar, shovelling, and Y groove of M2 among the neolithic Mehrgarh population fall within the range of traits for the southern (Sundadont) subdivision of the Mongoloid dental complex (Turner 1979). Thus, the neolithic Mehrgarh population may represent the westernmost distribution of the South- Southeast Asian dental complex (Lukacs 1989a).

Chalcolithic Mehrgarh (MR2, Period III)

Archaeology

The term chalcolithic describes an Old World phase that formed the late neolithic period (Mellaart 1970, after Eddy 1991) or post-dated the neolithic period (Jarrige and Meadow 1980), and existed prior to the bronze age. Chalcolithic cultures are distinguished

from earlier periods, or those with simpler technological systems, by the presence of ceramic vessels and tools or ornaments fashioned from copper and stone (Eddy 1991). Apparently, MR2 is the only chalcolithic cemetery in the greater Indus Valley or other parts of Pakistan (Samzun and Sellier 1985).

Microliths common to the earlier periods have disappeared, and new types of flint tools seem to be exclusively used during Period III. These lithic tools consist of large triangles and obliquely truncated blades, and many retouched flakes such as scrapers, notches and 'denticulates' (Lechevallier 1984). The blade segments were set into a groove of a wooden sickle and glued into place with a thick layer of bitumen. The serrated teeth of these sickles functioned as efficient harvesting tools, as indicated by the silica gloss ('polish') deposited on the working edge of many of the bladelets by the phytoliths common to the graminae (Lechevallier 1984; Piperno 1988). Two sickle fragments were found in the fill of a chamber from one of the grain storage buildings. Compared to earlier periods, there is also a decreased frequency of bone awls, but a drastic increase in frequency of burins during Period III. Lithic tools used in specialized craft activities are also represented. These include cylindrical drills of flint and microdrills of phtanite used in the production of very small beads from semi-precious stones, such as lapis lazuli, turquoise, and carnelian (Jarrige 1981). Bead production must have been a very important craft activity at MR2, judging from the great concentration of finished and unfinished microdrills and stone beads found within the corridors and outside of the structures. Fragments of perforated conch shells found at MR2 are evidence that shell bangles were also produced during chalcolithic times. Jarrige (1981) suggests that a bow drill was used in conjunction with these microdrills, a device that was recovered from much more recent stratigraphic levels at the site of Shahr-i Sokhta. Metallurgy was also practiced during Period III, as indicated by fragments of crucibles and a few copper ornaments. In addition,

terracotta figurines depicting humped bulls have been found at MR2, and reflect the increased importance of domestic cattle to Period III animal husbandry (Jarrige 1981).

The ceramics from Period III at Mehrgarh represent an increase in the quality and sophistification of pottery production from that observed in Period II (MR4), as well as a quantum leap in technological complexity compared to aceramic Period I (MR3). In the very early phase of MR2, the majority of the pottery sherds possess a fine fabric that is buff or red in appearance, and were likely thrown on a potter's wheel of some kind. This ware contrasts markedly to the very coarse chaff-tempered hand-made ware of Period II (Jarrige 1981). Apparently, the motifs consisting of dot-tipped rosettes and triangles or diamonds with hatched or plain patterns are also characteristic of the KGM II style of pottery from Phase II at Kili Gul Mohammad in the Quetta Valley, as well as from Mundigak (Fairservis 1956; Jarrige 1981:107; Lechevallier 1984). Also from the first half of the fourth millennium at MR2 are vessels that possess geometric motifs decorated with rows of birds and caprids, similar to the Togau A, KGM III, and Loralai Striped or Jangal painted ceramic styles (Jarrige 1981, 1984). This change in ceramic styles constitutes the transition to the later phase of Period III. In a recent review of the ceramic sequence, Samzun and Sellier (1985) suggest that three successive pottery phases existed during Period III. Phase 1 consists of small quantities of the KGM II style of pottery, but some basket ware and very coarse ware characteristic of the early neolithic still exist. Phases 2 and 3 described by Samzun and Sellier (1985) encompass the second phase described by Jarrige (1981). Phase 2 is represented by a decrease in frequency of basket ware, and the appearance of sherds decorated with figurative motifs (birds and caprids) associated with hatched triangles and squares. The final phase of Period III is represented by large quantities of pottery decorated with friezes of diverse, stereotyped and stylized figurative motifs (Samzun and Sellier 1985). Reconstruction of some of the ceramic vessels indicates that all were flat-bottomed, a trait shared with pottery from many other chalcolithic sites in

the region (Jarrige 1985). The vessels varied in size, and many were globular in shape with a pronounced lip. Also, some flat dishes were found in the third phase of Period III (Samzun and Sellier 1985). Based on the large concentration of sherds of fine wheel-thrown ware, Jarrige (1984) theorizes that an industry for the mass-production of ceramic vessels existed at MR2. Furthermore, Jarrige (1981) emphasizes that social and economic networks were shared between chalcolithic Mehrgarh and many other contemporary sites to the west and north, based on the presence of local variants of these styles of pottery. Jarrige (1984) further stresses that a continuous cultural tradition, especially with regard to craft activities, linked the very latest phase of Period III at Mehrgarh with urban civilizations at the edge of the Indus Valley and at Mohenjodaro.

Architectural Styles

As with Period I, most of the structures in Period III probably functioned as grain storage facilities. The Period III structures possessed no evident doorways, and were rectangular in shape with four or more small chambers. But in contrast to the Period I buildings, the structures of Period III were more elaborate, with rows of long chambers separated by a central corridor (Meadow 1984a:327). Apparently, the majority of domestic activities and those related to craft production were practiced in these corridors or outside of the buildings. Meadow (1984a) takes this as limited evidence that the buildings at chalcolithic Mehrgarh were all used as central storage facilities. It should be noted that Meadow's assertion is in contrast to claims by Lechevallier and Quivron (1981, 1985) for the presence of 'houses' in both Periods I and III. In addition to the compartmented mud-brick buildings, Samzun and Sellier (1985) emphasize that two additional types of remains were found in the excavations of MR2. These consist of a kiln area for firing pottery, and craft-production areas where the working of semi-precious stones or sea shells, as well as metallurgy, was practiced. With regard to seasonal use of the Mehrgarh area, Meadow

(1984a:328) states that "the population would have concentrated during the winter growing season, a more dispersed pattern perhaps being characteristic of the hot summer months." This statement follows Meadow's notion that transhumance was an important aspect of life at Mehrgarh during at least the fourth millennium B.C.. Herders may have driven their livestock down from the upland grazing areas during the winter months, at which time they probably congregated at Mehrgarh. Minerals and other raw materials obtained in the highlands may have been traded for finished products made locally. This scenario also envisions the trade and/or slaughter of animals culled from the herds brought down from the summer range. With the coming of spring, herders would have again driven their herds from the Kachi plain to the more verdant and cooler upland valleys. According to Jarrige (1981), the limited architecture uncovered at Period III is not indicative of a proto-urban settlement, but instead reflects a continued tradition for seasonal use of the site as a craft center or market place.

Archaeological Evidence for Diet and Food Processing

The chalcolithic Mehrgarh (MR2) population practiced an incipient agricultural lifeway, based on the presence of fine ceramic vessels and also from faunal and floral remains. Generally, the food production practices of the chalcolithic Mehrgarh population encompassed the cultivation of mixed cereal grains, and the herding of cattle, sheep and goats (Jarrige and Meadow 1980). Cultivation of several types of wild and domesticated cereal grains (barley and wheat) was practiced during Period III, as well as the herding of predominantly domestic cattle, sheep and goats (Jarrige 1984). Generally, a type of agriculture known as 'rabi' was practiced at Mehrgarh, in which crops were sown in the winter season and harvested in the spring (Meadow 1989).

The agricultural diversification observed at MR2 was even greater than that at MR3 (Jarrige 1981; Costantini 1984; Costantini and Costantini Biasini 1985; Meadow 1989).

According to Costantini (1984), several types of wild and domesticated grains were cultivated during Period III: five species of wheat (Triticum monococum, T. dicoccum, T. aestivum compactum, T. aestivum sphaerococcum, and T. aestivum durum), two species of barley (Hordeum distichum and H. vulgare), and oats (Avena sp.). Stones of the date (Phoenix dactylifera) were not found in strata of Period III as they were during Periods I and II. Cotton seeds, which were tentatively identified from deposits of Period IIB (fifth millennium B.C.), have not been recovered from strata of chalcolithic Mehrgarh (Costantini 1984; Meadow 1989). However, stones from the fruit of the jujube (Zizyphus jujuba), a native tree that bears small fruits, have been found during the chalcolithic as well as during earlier periods (Meadow 1989). Generally, the previous discussion regarding the botanical evidence for agriculture during Period I applies also to Period III, with a few exceptions. For instance, Costantini (1984) reports that the initially very low presence of naked sphaerococcoid wheat (T. durum) in the aceramic neolithic and early chalcolithic increases dramatically in Period III. This, coupled with a lower proportion of an increasingly round form of naked barley, compared to Period I, is indicative of wheat becoming a more important dietary constituent by the chalcolithic period (Meadow 1989). As mentioned previously, Meadow (1989) believes that the fully domestic wheats present at Mehrgarh Period III were probably introduced into the area from the west. Evidence for this comes from the presence at MR2 of bread wheats (Triticum aestivum), which may have been a hybrid of introduced wild forms of Triticum and a closely related plant (Aegilops squarrosa).

According to Jarrige (1985), many circular pit hearths containing heavily-burnt and fire-cracked pebbles have been uncovered at MR2. Many ceramic pots also contained these cracked pebbles, indicating that heated stones were used to cook food during Period III, rather than through direct heating of the contents of a pot placed on a flame (Jarrige 1985). The author also suggests that meat was roasted in these hearths, rather than being cooked in

a vessel, because of the presence of many charred animal bones. Certainly, the presence of a large number of ceramic vessels at chalcolithic Mehrgarh indicates that most foods were cooked prior to consumption. Whether the wheat cultivated at MR2 was prepared in the form of an unleavened cake or chapati, as is common among modern villagers of Mehrgarh, or in the form of a gruel is uncertain from the archaeological evidence presently available. The former would require the use of a grinding stone to prepare the grain, while the latter would simply require the separation of the kernels from the seed heads.

Although some studies have reported a lack of grinding stones in the MR2 artifact catalogue (Lechevallier 1984; Samzun and Sellier 1985), more recent investigations in Sector H (Meadow, personal communication 1991; Samzun 1988) have recovered numerous groundstone artifacts (pestles, mortars, grinding stones) from several structures. These tools could have been used in the preparation of wheat and other grains into flour for use in baking a bread or cake. For example, the groundstone artifacts from MR2 deposits are apparently indistinguishable from those present during the Mature Phase at Harappa (Kenoyer, personal communication 1992), where indisputable evidence exists for the use of such tools for grinding and processing grains (cf. succeeding section for discussion of Harappan groundstone artifacts). However, many of the pestles and grinding stones recovered from MR2 deposits, such as those from Locus 14 of Structure I, may have instead been used in the manufacture of bone tools ("fleshers," needles, pointers, awls) and/or for processing animal products, because bone artifacts as well as unaltered bones of large mammals were found in burnt fill adjacent to this structure (Samzun 1988). Until additional analyses of Period III groundstone artifacts are undertaken, such as for macrobotanical remains, chemical residues or microwear patterns (Miller 1991), the actual function of these groundstone tools will remain in question.

The groundstone artifact assemblage in Period III contrasts with Period I, where according to Jarrige (1981:99), the presence of small numbers of "heavy-duty tools" in the

upper levels suggests that neolithic occupants of Mehrgarh consumed barley and wheat in the form of a baked cake. However, it should be noted that the majority of these heavy stone tools from Period I levels were actually axes and adzes (Lechevallier 1984), while the few ground stone implements found in some Period I graves may have been used for pulverizing red ochre.

The degree to which grains were processed prior to consumption has direct bearing on the kind of dental microwear pattern one would expect to find among Period III (or Period I) inhabitants. The relationship between dental microwear and food processing technology is examined in Chapter VII.

In general, the faunal remains from chalcolithic strata of Mehrgarh have not yet been fully analyzed or reported, but preliminary discussion of the faunal assemblage is provided by Meadow in a series of reports (1981, 1984b, 1989). By the end of the aceramic neolithic period (6000 B.C.), hunting of wild ungulates was less commonly practiced, being replaced instead by the keeping of domestic goats, sheep, and cattle. Breeding of cattle became the predominant form of animal exploitation after the beginning of the fifth millennium, and continued throughout Periods II and III (Jarrige 1985). As mentioned previously in the discussion of the Period I fauna, Meadow (1984b) believes that selective breeding was not characteristic of the domestication of zebu cattle through the chalcolithic period. Meadow (1981) provides a partial list of identified fauna from chalcolithic Mehrgarh, as well as a detailed description of skeletal elements and size comparisons with regard to the degree of domestication existing during Period III. Many biases are introduced into the interpretation of the faunal analyses by the specimen count method, as well as by the 'talash' method of specimen recovery, which involves carefully picking through the excavated but unsieved sediments by hand (Meadow, personal communication 1991). In this regard, Meadow (1981:150) cautions that "At best, a count, however performed, is a representation of what was recovered and, hopefully, at least a

pale reflection of what was deposited." As a consequence, the importance of large mammals is overrepresented by the specimen counts. However, this bias is partially counteracted by Meadow's assessment of the relative proportions of large and medium mammals based on bone count and bone weight, which included unidentifiable fragments of bone. One noteable consequence of the problem in identifying fragmentary material is that empirical discussions should probably focus only on broad size categories of mammals, rather than by specific taxon. Meadow (1981) concluded that the frequencies, and thus importance, of large mammals increased through time at Mehrgarh. The bones of domesticated goat, sheep, and cattle (Bos sp.) are represented at MR2, but the evidence for an increase in proportion of large mammals slightly favors the importance of cattle to the diet of chalcolithic Mehrgarh. Also, slightly more identified skeletal elements belong to cattle than to goat or sheep (Meadow 1981). However, with regard to the keeping and slaughtering of cattle, Meadow (1981) readily admits that some of the bones identified as cattle may actually be those of the water buffalo (Bubalus arnee), a wild species that was indigenous to the swamps and rivers of the area. Apparently, these remains continue to be represented in later deposits after bones of the swamp deer (Cervus duvauceli) are no longer present. The percentage of standardized counts for cattle bones decreases from more than sixty percent in Period II (MR4) to approximately thirty-five percent in Period III, a figure which is similar to that for the late phase of Period I (Meadow 1989). Nevertheless, the remains of cattle still represent a higher proportion of all fauna at MR2 than they do during the early neolithic (aceramic) phase at MR3. Also, one must keep in mind Meadow's contention that the raising and slaughtering of cattle represent a significantly greater proportion of meat, in contrast to goat or sheep, in the chalcolithic Mehrgarh diet. Basically, the evidence from the morphology of goat (Capra) and sheep (Ovis) bones is equivocal as to whether they were free ranging (wild) or domestic, herded or hunted. But the evidence is stronger for sheep having been herded, because size

diminution is noticeable in the Period II collection compared to that of Period I. However, no such diminution in the size of goat bones occurred between the later phase of the neolithic and the chalcolithic periods at Mehrgarh (Meadow 1981). A more complete list of ungulates from Mehrgarh Period III, identified by faunal remains, is provided in a recent report by Meadow (1989). Wild fauna include: khur or onager (Equus hemionus), wild boar (Sus scrofa), barasingha or swamp deer (Cervus duvauceli), and chinkara or gazelle (Gazella bennetti). Meadow (1989) considers the presence of the wild water buffalo (Bubalus arnee), wild goat (Capra aegagrus), and urial or wild sheep (Ovis orientalis) as possible but questionable. Period III domestic ungulates include: zebu or humped cattle (Bos indicus), domestic goat (Capra hircus), domestic sheep (Ovis aries), and possibly the domestic water buffalo (Bubalus bubalis). Additional evidence for the domestication of zebu cattle at chalcolithic Mehrgarh is provided by figurines of humped cattle, found in strata belonging to MR2 (Meadow 1984b).

Burial Complex

According to Samzun and Sellier (1985), the MR2 cemetery is located to the west of the two main areas of mud-brick buildings. Nearly 100 individuals have been recovered from chalcolithic Mehrgarh, although many of the bony remains are very fragmentary and not well preserved (Lukacs, unpublished catalogue; Samzun and Sellier 1985). Samzun and Sellier (1985) indicate that up to 25 individuals may yet to be excavated from the chalcolithic Mehrgarh cemetery. Originally, the density of the MR2 graveyard may have been greater than 1300 individuals, based on the density of the R2J sounding and extrapolation for the estimated area covered by the original cemetery, prior to its alteration by geomorphic forces (Samzun and Sellier 1985).

The burial practices of chalcolithic Mehrgarh share some similarities with, but also differ from those of neolithic Mehrgarh (Samzun and Sellier 1985). For example, both the

neolithic and chalcolithic populations buried their dead with the corpse lying on the left side, with the skull toward the east but facing south. The arms and legs are tightly flexed, indicating possible wedging or binding of the bodies (Samzun and Sellier 1985), and the hands are near or under the face (Lukacs and Hemphill 1991). Ornamentation found on a single male and many of the female skeletons include perforated sea shell and turquoise beads. Many of the very common cylindrical bead necklaces are made of baked steatite and semi-precious stones, such as lapis lazuli and carnelian. The chalcolithic burials differ from those of neolithic Mehrgarh in that the former possess fewer grave goods, but the treatment given the corpse prior to burial is also more diverse. This includes separate treatment of children, collective burials, and re-inhumation or secondary burial at chalcolithic Mehrgarh. In addition, burial structures at MR2 are nonexistent, with the corpse interred only in a burial pit. However, individuals were often found with the skull resting on a mud-brick "pillow" (Lukacs and Hemphill 1991). This lack of burial structures during Period III is in strong contrast to the funerary structures common to Period I, in which single chambers consisting of a single mud-brick wall were present. Also, pottery was a relatively uncommon burial offering during Period III (Samzun and Sellier 1985). In fact, only two vessels of buff ware with black geometric and zoomorphic designs were found within the context of Period III burials. Samzun and Sellier (1985) conducted a demographic analysis of the MR2 cemetery in order to distinguish any gender or age-based differences in burial practices. Their results revealed a slightly lower proportion of adult males (42%) than adult females (58%), a difference which is not significant when compared to a balanced sex ratio. However, infant burials at MR2 are very underrepresented in the sample, and those present do not possess any grave goods. The authors hypothesize, based on this 'negative' evidence, that a cultural bias existed at MR2 against the burial of infants and very young children. In addition, within the primary burials no sex differences were observed with regard to the type of burial 'structure'. With

regard to treatment of the corpse, however, the existence of head ornaments on female individuals may be indicative of their high status among the inhabitants of chalcolithic Mehrgarh (Samzun and Sellier 1985). Although partial continuity is indicated between neolithic and chalcolithic Mehrgarh burial customs, the authors conclude that the differences are more dramatic. For example, side-walled graves are common at MR3, while burial pits are found at MR2. Also, children seem to have higher status at MR3, based on the greater proportion of infant and child burials and the associated ornaments. These differences at MR2 may indicate a more complex social system during chalcolithic times at Mehrgarh, in which young children and infants were segregated from any burial rituals, and in which certain women from the population were accorded special status (Samzun and Sellier 1985).

Osteology

In contrast to the MR3 collection, many of the cranial and dental remains from MR2 have been assessed for sex, age at death, and stature (Lukacs, unpublished catalogue; Samzun and Sellier 1985). Individuals from which specimens were utilized in the present dissertation research are primarily adults, with one pre-adolescent child represented (Table 3.1). Gender representation is divided equally within the sample of four adults, but the child was too immature for assignment of sex based on secondary sexual characteristics. A preliminary osteological analysis of twenty individuals (six males, 14 females) from MR2 revealed that sexual dimorphism for stature was 8.0%, based on a male mean of 171.7 cm and a female mean of 159.0 cm (Lukacs and Hemphill 1991). However, sexual dimorphism in tooth size (discussed below) was even greater. At the present time, no additional osteological data are available for Mehrgarh Period III.

Dental Morphometrics and Pathology

The following discussion consists of a brief review of the dental morphometric analyses (Lukacs and Hemphill 1991) and of the dental pathology profiles for the peoples of chalcolithic Mehrgarh (Lukacs 1985b; Lukacs and Minderman 1992). Fluorosis was observed in two specimens from the Mehrgarh Period III skeletal collection (Lukacs et al. 1985). As previously discussed in the section on MR3 dental pathology, a distinct difference in the incidence of fluorosis was found between the MR2 and MR3 permanent dental samples (Lukacs 1985b). According to Lukacs, the generally younger age class of the MR2 population may have ameliorated the expression of dental fluorosis, simply because of the shorter period for consumption of fluoridated water. However, experimental laboratory evidence is required as further proof of this interpretation.

Additional dental pathology analyses of the chalcolithic and neolithic Mehrgarh skeletal collections are presented by Lukacs and Minderman (1992). A general increase in the prevalence of dental disease accompanied the increasing agricultural intensification documented archaeologically for neolithic to chalcolithic levels at Mehrgarh. Although most differences were not statistically significant, chalcolithic individuals at Mehrgarh exhibited significantly more dental caries than did neolithic individuals, while a significantly greater incidence of dental calculus was observed for the neolithic peoples of Mehrgarh. An increased prevalence of antemortem tooth loss, pulp exposure and dental abscesses was also documented among the people of chalcolithic Mehrgarh. In addition, enamel hypoplasia occurred frequently, sometimes severely, at both Mehrgarh sites, an indication that both populations were under nutritional or disease stress during the developmental period of tooth formation. Lukacs and Minderman suggested a different etiology for pulp exposure among the two dental samples. Heavy dental attrition was suggested as a causative factor among the neolithic series, while carious decay was implicated for the chalcolithic series. Furthermore, the authors suggested that the combined

stresses of dental caries and dental attrition were responsible for the greater prevalence of antemortem tooth loss at MR2, while among neolithic peoples at Mehrgarh antemortem tooth loss was again due primarily to attrition (Lukacs and Minderman 1992). Further evidence for this difference between the two dental series awaits the systematic analysis of attrition, based on ordinal scales (Molnar 1971a; Scott 1979a) (see Chapter VI).

A comprehensive and comparative dental morphometric analysis of the chalcolithic and neolithic Mehrgarh skeletal collections is presented in a recent monograph by Lukacs and Hemphill (1991). Generally, no significant differences for tooth size were observed between the MR3 and MR2 populations. With regard to individual crown dimensions, only the buccolingual diameter of M_1 exhibited a significant difference between the MR3 and MR2 teeth. Furthermore, neither the individual tooth crown areas (except for M_1) nor the summed or cross-sectional crown areas were found to be significantly different between the inhabitants of chalcolithic and neolithic Mehrgarh (Lukacs and Hemphill 1991). However, when the two dental samples were sub-divided by sex, these investigators found significant differences in the size of permanent teeth. Specifically, the upper and lower canines were found to be the most sexually dimorphic teeth, while the least sexually dimorphic tooth in the MR2 sample was the maxillary lateral incisor. With regard to the dimensions of the deciduous teeth, the MR3 and MR2 samples were not significantly different from each other, except for smaller mesiodistal diameters in the deciduous incisors and a smaller crown area for the upper deciduous incisor of the MR2 sample (Lukacs and Hemphill 1991). On the basis of calculated morphological trait frequencies, maxillary molars from chalcolithic Mehrgarh are morphologically conservative compared to the anterior teeth. For example, the latter consistently exhibit lingual shovelling and the distal accessory ridge is frequently present. But maxillary molars exhibit only a low to moderate frequency of occurrence of the metaconule. Also, the commonly present Carabelli's trait is expressed conservatively as pits and grooves. However, mandibular anterior teeth are

more conservative than their isomeres, while mandibular molars are morphologically more complex than their isomeres. For example, M_1 commonly exhibits the Y-groove, which becomes reduced with posterior progression through the tooth class. The hypoconulid is most developed on the M_1 and least developed on the M_2, while the M_3 exhibits an intermediate form of expression. Carabelli's trait is commonly expressed as pits and grooves on dm^2, although few MR2 deciduous teeth are preserved (Lukacs and Hemphill 1991).

Lukacs and Hemphill (1991) compared the trait frequencies between the Period I and Period III Mehrgarh samples. Their results revealed that only a small number of tooth-trait combinations were significantly different between the samples. For example, the chalcolithic Mehrgarh sample exhibited significantly greater hypocone development on M^2, and Carabelli's trait is exhibited at a much higher frequency on the upper molars of Period III individuals. The authors suggest that, while tooth size appears to remain stable over time, the chalcolithic teeth are morphologically more complex than the teeth from the neolithic Mehrgarh population, based on these limited trait differences. In their report, Lukacs and Hemphill (1991) present additional comparative odontometric data in order to place the two Mehrgarh populations in a regional perspective. Summed cross-sectional crown areas for both the chalcolithic and neolithic Mehrgarh samples are smaller than mesolithic Mahadaha, but larger than those of Sarai Khola. The authors point out that these results fit generally with the predictions of Brace and Montagu (1977, after Lukacs and Hemphill 1991) for a morphocline of decreasing tooth size concomitant with increasing technological advancement for food production and preparation. For example, the authors emphasize that the small size of Sarai Khola teeth is consistent with the site location in the upper Indus Valley where intensive agricultural subsistence practices have a great antiquity (Lukacs 1983b; Lukacs and Hemphill 1991). Although the MR2 dental sample from which percent sexual dimorphism could be calculated is small, Lukacs and Hemphill (1991)

conclude that the inhabitants of chalcolithic Mehrgarh exhibit marked sexual dimorphism in tooth size, and in the range of percent dental size dimorphism calculated for the Upper Paleolithic by Brace and Ryan (1980). The sexual dimorphism for tooth size at chalcolithic Mehrgarh is especially unusual in light of the hypothesis proposed by Brace and Ryan for post-Pleistocene dental reduction and decreased sexual dimorphism in association with the Probable Mutation Effect, relaxed selection pressure, and advanced technological development. The analysis of dental abrasion features from MR2 by Lukacs and Pastor (1988) also indicated that sexual division of labor may have been practiced for occupational tasks requiring the manipulative use of the teeth.

The morphological features of neolithic and chalcolithic Mehrgarh dentitions were also compared with the dental morphology of four other prehistoric South Asian populations (Lukacs and Hemphill 1991). The seven tooth-trait combinations found to be the best discriminators between the six populations were employed in three multivariate analyses. The results of cluster analyses confirmed the fact that Sarai Khola, an early iron age (1st millennium AD) sample from northern Pakistan, is archaeologically and osteologically distinct from other northern Indus Valley prehistoric populations. Furthermore, the neolithic Mehrgarh sample exhibited closer affinities to the late chalcolithic sample (1700-700 B.C.) from Inamgaon and the late bronze age-early iron age sample from Timargarha in northern Pakistan than to the chalcolithic sample from Mehrgarh. This hint for a lack of biological continuity at Mehrgarh was further confirmed by results of a multidimensional scaling analysis (Lukacs and Hemphill 1991). However, this analysis revealed some affinity between chalcolithic Mehrgarh and Timargarha, although still generally separating MR2 from the other sites. In addition, the mesolithic Indian site of Mahadaha is separate from the cluster of neolithic Mehrgarh, Inamgaon, Timargarha, and chalcolithic Mehrgarh, but is especially distinct from the Sarai Khola sample. The distinctiveness of Mahadaha is not surprizing in light of its geographical and

temporal status, although the lack of affinity with the more proximate peninsular Indian site of Inamgaon is rather unusual. Overall, Lukacs and Hemphill (1991:114) conclude that differences in dental morphology between MR3 and MR2 "do not indicate biological continuity in a regionally isolated lineage, but tentatively suggest moderate levels of gene flow coupled with some degree of random genetic drift", and furthermore the "specimens from the neolithic levels at Mehrgarh show much closer affinities to the late chalcolithic series from Inamgaon than to the chalcolithic sample from Mehrgarh." Therefore, the biological discontinuity between the two Mehrgarh populations implies "the moderate gene flow from rural populations with basic technologies into the Mehrgarh gene pool sometime after Period Ib (6000 B.C.) but prior to phase 2 of Period III (4500 B.C.), coupled with the effects of periodic genetic drift" (Lukacs and Hemphill 1991:114). The authors suggest that although some genetic continuity exists "within the Indus Valley from neolithic times to the early Iron Age" (ibid:114), the discontinuity between neolithic and chalcolithic Mehrgarh suggests the possibility for periodic disruptions by gene flow from the western Himalayas or beyond. This new biological evidence from Mehrgarh contrasts with cultural continuity between the neolithic and chalcolithic periods (Jarrige 1981, 1985, 1989). Instead, the changes in technology and culture documented at Mehrgarh Period III may have been the result of the incursion into the area of nearby and biologically different populations bearing novel and diverse techno-cultural complexes.

Harappa

The following review of the archaeological literature on the Mature Phase (Urban Phase) of Harappa is brief, but encompasses an overview and provides citations for more definitive sources with regard to the following topics: location of the site; chronology; archaeology, consisting primarily of a description of the cemeteries from which samples were derived (including the burial context and ritual offerings); the archaeological evidence

for food processing and diet; and the physical anthropology, a review of osteological and paleopathological analyses, and a review of the dental pathology and morphometric analyses. The site of Harappa is documented in the following non-inclusive list of published works: Allchin and Allchin (1982); Dales (1989); Dales and Kenoyer 1992, n.d.-a, n.d.-b (in press); Fagan 1977; Fairservis (1975); Kenoyer (1989); Meadow (1991); Possehl 1982, n.d. (in press); Vats (1940); and Wheeler (1968).

Location and Chronology

Harappa is located in Punjab Province of northeastern Pakistan, along the banks of the Ravi River, a tributary of the Indus River. Although Harappa was first publicized by Charles Masson in 1826, it was not until 1875 that exploratory excavations were undertaken by Alexander Cunningham. Excavations at Harappa began in 1921 under the direction of Sir John Marshall, Director-General of the Archaeological Survey of India (Dales 1989:127). The results of the excavations at Harappa were reported by Vats (1940), and summarized by Wheeler (1947).

Many sites belonging to the Harappan Tradition have been discovered throughout Pakistan and in parts of northwestern India (Weber 1992a:7). The Mature Urban Phase of the Harappan Civilization is generally considered to have lasted for approximately 500 years, from about 2500 B.C. to 2000 B.C. (Possehl 1990; Possehl and Rissman 1992; Shaffer and Lichtenstein 1989:12). Based on evidence from the sites of Kalibangan, Allahdino, Balakot, and others, these archaeologists argue that the transition from the Pre-urban Phase to the Urban Phase took between 100 and 150 years, and the transition to the Post-urban Phase was probably as rapid.

Archaeological Evidence for Diet and Food Processing

Vats (1940) and Wheeler (1947, 1968) suggested that, during the Mature Phase at Harappa, wooden pestles were used for pounding grain in a wooden mortar socketed into a floor of baked mud bricks. These architectural features consisted of concentric rings of brick located on large brick platforms adjacent to the granaries (e.g., Wheeler 1968:32, Plate IV-B). Wheeler contended that the brick platforms served as the central location for threshing and grinding the cereal grains grown during the Mature Phase. However, Kenoyer and other contemporary archaeologists believe that these brick platforms were neither used for threshing nor grinding of grains (Kenoyer, personal communication 1992). Instead, the threshing of the grain was probably done in the fields, whereas processing of the grain into flour may have been done within individual households using groundstone tools.

The food processing technology during the Mature Phase of Harappa has yet to be systematically analyzed and documented (e.g., Fairservis 1975) but, according to Kenoyer (personal communication 1992), consisted of numerous groundstone artifacts (pestles, manos, and metates) fashioned from various lithic materials, such as quartzite, sandstone, and basalt. Sources of raw materials for such artifacts are located in the mountains to the west of the site, and were probably used by the earlier inhabitants of Mehrgarh as well as Harappans. Manos of terra cotta have also been found at many Harappan sites, including Harappa. Although the quartzite and sandstone grinding stones range in texture from fine to coarse-grained, those of fine to medium-grained material were probably used for food processing, because more of these exhibited concave surfaces (Kenoyer, personal communication 1992). A flat surface is more often present on groundstone fashioned from coarse-grained rock of the same parent material as the finer grained artifacts. Presumably, a flat surface would indicate a function other than food processing, although it is still

possible that some of the coarse-grained quartzite and sandstone grinding stones and pounders were used for processing grains.

Based on identified or assumed botanical evidence at Mohenjo-daro, Rangpur and other Sind sites, crops cultivated within the Indus Valley core area during the Mature Phase included wheat, barley, peas, lentils, sesamum, mustard, cotton, figs, jujubes, dates, melons, mangos, pomegranates, and bananas (?) (Allchin and Allchin 1982; Fairservis 1975; Weber 1992a, 1992b). However, botanical evidence for many of these plants has not been found at Harappa itself. Domesticated varieties of wheat and barley were the principle cereal crops cutivated during the Mature Phase at Harappa (Vishnu-Mittre and Savithri 1982; Wheeler 1968). Carbonized seeds of wheat and barley were recovered during the recent excavations at Harappa (Dales and Kenoyer, n.d.-a), along with seeds of legumes, including Lens, and several species of Lathyrus, Pisum, and Cicer. The samples also included many wild seeds of "weedy" types of plants, as well as a variety of wild grasses including Amaranthus/Chenopodium types, Trianthema triguetra, and Digera muricata. Remains of Zizyphus sp. and Albizia procesa/lebbeck were also collected from the Mature Phase levels at Harappa. To date, root or tuber crops have not been documented from Mature Phase horizons at Harappa.

The seeds of many species of millet, a group of unrelated forage grasses with coarse seeds, were identified from Rojdi, some for the first time in Mature Phase strata. Four of these millets were found in significant proportions at Rojdi: Eleusine coracana, Setaria italica, Panicum miliare, and Sorghum bicolor (Weber 1992a, 1992b). From his work at Rojdi, Weber (1992a, 1992b) contends that plant gathering and cultivation, as well as herding and hunting, were practiced by Harappans. In fact, Harappans should be considered "agro-pastoralists" because of the important role played by both plants and animals in the Harappan subsistence system. Most attention by archaeologists and palaeobotanists has centered on the cultivated cereal grains recovered from Harappan sites.

However, the recent palaeobotanical work at Rojdi has provided evidence for a substantial contribution from wild plant gathering to the subsistence system. The gathering of wild plants during the Mature Phase at Harappa has not been documented, but Weber (1992a:179) emphasized that "both gathering and cultivation were important to the Harappan civilization" and that "cultivation was by no means the sole source of plant food."

Domesticated bovids, the principle animals raised and herded at Harappa, were used for food, clothing, and traction (Meadow 1991a, n.d.). Indian humped cattle (Bos indicus) were most predominant, and sheep (Ovis aries) and goat (Capra hircus) were also kept in smaller numbers. Of these smaller bovids, Meadow (1991a) feels that sheep were especially important among Harappans for their wool, princpally, and also for meat, and fat. At Rangpur, the Mature Harappan Phase (Period IIA) also revealed Indian humped cattle, as well as domestic buffalo (Bos bubalus), goats (C. hircus), sheep (Ovis vignei), and domestic pig (Sus scrofa cristatus) (Fairservis 1975:307, after Nath 1963). Large fish, such as catfish and carp, and molluscs were also consumed by at least some segments of the population at Harappa (Belcher 1991; Meadow 1991a, n.d.). Wild species of mammals, previously undocumented at Harappa, were found in relative abundance during recent excavations (Meadow 1991a, 1991b). These species include the Indian elephant (Elaphas maximus), one-horned rhinoceros (Rhinoceros unicornis), wild boar (S. scrofa), chital or spotted deer (Axis axis), hog deer (Axis porcinus), barasingha or swamp deer (Cervus duvauceli), nilgai (Boselaphus tragocamelus), blackbuck (Antilope cervicapra), and gazelle (Gazella bennetti) (Meadow 1989). In his most recent analysis, Meadow (n.d.) suggests that the occurrence of different taxa at widely divergent sections of the ancient city is indicative of the differential access by Harappans to various animal resources.

Burial Complex

Cemetery R37, belonging to the Mature Urban Phase, was described in reports on the original excavations at Harappa (e.g., Bose 1963; Mughal 1968; Wheeler 1947) and from more recent excavations (Dales and Kenoyer, n.d.-a). All dental specimens used in my research were derived from individuals interred in graves at cemetery R37 (Table 3.1), and excavated during the 1987 and 1988 field seasons under the direction of Drs. John R. Lukacs and Kenneth A.R. Kennedy.

Based on the lack of elaborate ritual offerings, Wheeler (1968) claimed that the R37 cemetery contained "average" citizens from the mature Harappan phase, rather than individuals of status. However, more recent evidence from the 1987 and 1988 field seasons revealed more elaborate burial goods and ornamentation, for both male and female individuals, than previously found in cemetery R37 (Dales and Kenoyer, n.d.-a, n.d.-b). These artifacts included both simple and more complex pottery vessels, as well as necklaces, bracelets, and a headdress. The ornaments were fashioned from shell, carnelian, jasper, steatite, onyx, serpentine, and occasionally gold (Dales and Kenoyer, n.d.-a, n.d.-b). Despite these sometimes elaborate burial ornaments, Dales and Kenoyer (n.d.-a) contend that the interments represent individuals of relatively similar socio-economic segments of Harappan society. Several individuals were buried in wooden coffins, but no association existed between these and burial ornamentation or pottery. The burial position was primarily extended and supine with a north-south orientation, and with the head to the north.

Osteology and Paleopathology

A detailed morphometric analysis of the Harappan skeletal remains, excavated prior to and during the 1987 and 1988 expeditions, was provided by Kennedy (n.d.-a, n.d.-b), who elaborated upon his earlier work and that of other investigators (e.g., Bose 1963;

Gupta et al. 1962; Dutta 1972; Kennedy 1982a). The more recent excavations at Cemetery R37 yielded the discrete remains of 25 individuals, 9 crania, 6 mandibles, and hundreds of fragmentary and disarticulated skeletal elements, including numerous loose teeth (Lukacs, n.d.). Of the complete material, more than half of the individuals were young adults (16-34 years), and the sex ratio was nearly equal for those skeletons where sex was determinant (Kennedy and Lovell, n.d.). The dental sample I used in my microwear study included individuals in the young adult category, primarily, although two juvenile individuals are also included. Also, females are slightly better represented in the sample than males (Table 3.1).

Kennedy (1982a) hypothesized that a continual process of acculturation of tribal peoples into lower 'caste' rural and outlying peasant populations, and subsequent emigration to urban Harappa population centers (e.g., as laborers), can explain the slight variation he found in cranial morphometrics of Harappans from Cemetery R37. Using a regional perspective, cranial and dental metric and non-metric data for Harappans were compared with a large data set from other sites of South Asia and the Near and Middle East (Hemphill et al. 1991). Their analyses revealed that Harappans had biological affinities with contemporaneous populations residing to the west, on the Iranian Plateau and in the Near East. The closest biological affinities of Mature Phase Harappans was found to be with individuals from the Iranian site of Tepe Hissar 3, as also shown earlier by Dutta (1984a).

Based on a lack of osteological and dental indicators of growth interruption (Harris lines and enamel hypoplasia, respectively), Kennedy (1982a; Kennedy and Lovell 1989) contended that Mature Phase Harappans were generally well-nourished. Lovell (n.d.) also found only a very low incidence of Harris lines among the skeletal remains she examined from the recent excavations. She noted, however, that this evidence could be skewed by the age profile of the sample, because growth arrest lines in older individuals could have

been remodelled. Of the few pathological conditions present, arthritis was the most prevalent. All other paleopathological indicators showed that the residents of Harappa were healthy and had adequate diets (Lovell, n.d.). However, Lukacs (1992, n.d.) showed that the Harappan dental pathology profile includes a very high incidence of enamel hypoplasia, with lower incidences of alveolar resorption, calculus, and ante-mortem tooth loss (AMTL). While the frequency of dental caries was at an intermediate and non-significant level, Lukacs contended that the true caries rate was even higher when the teeth lost ante-mortem were considered (i.e., AMTL was due to the combined factors of caries and pulp exposure). He suggested that these dental pathology indicators, which are characteristics of agricultural subsistence systems generally, had biological significance for Harappans, especially for females.

There is no evidence for higher status accorded to Harappan females, based on the method of interment or ritual offerings. In fact, much of the archaeological evidence at Harappa is suggestive of an egalitarian society, with little difference by class or occupational guild. However, such a conclusion is not supported by the pattern of dental disease among Harappans, especially between the genders. Sexual dimorphism is present at Harappa for paleopathological indicators of dental health (Lukacs 1992, n.d., personal communication 1991). For example, the incidence of enamel hypoplasia and dental caries among females is much greater than for males. Such evidence is indicative of sex differences for diet at Harappa. Compared to Harappan males, females (children and adults) may have had a diet that was reduced in protein, but higher in carbohydrates obtained from processed grains. Among other scenarios, the higher frequency of enamel hypoplasia among adult females may have been influenced by the high carbohydrate-low protein diet of their mothers (Lukacs 1992).

CHAPTER IV

MATERIALS AND METHODS

Introduction

All whole teeth, negative impressions, and epoxy replicas, which were originally part of a blind sample, were identified with alphabetic labels. These identification labels were used during all phases of the replication process, optical analyses, SEM analyses, and digitizing (data collection) sessions. The true identities of the specimens were revealed to the author in stages, but not until most of digitizing work had been accomplished.

A description of the permanent tooth specimens, including provenience and the age and sex of the prehistoric individuals, was provided in Table 3.1. The biological age (i.e., age at death) and other osteological parameters of individuals in the sample were determined by other investigators (see Chapter III) using standard osteological methods and techniques. Whole teeth (M_1's and M_2's) from neolithic and chalcolithic Mehrgarh were collected during several field seasons by Dr. John R. Lukacs, who provided them to me as part of the blind sample for use in my research. The sample from chalcolithic Mehrgarh included permanent first and second molar pairs from four adults and a juvenile, and a permanent M_1 from a young child (N = 11). Three molars were collected from two adults interred in the neolithic level at Mehrgarh (N = 3). These 14 specimens, which comprise slightly less than 50% of the original blind sample, were cleaned and cast using the methods described below. Prior to cleaning, each whole tooth was examined for the presence of preservatives, museum preparation artifacts, or postmortem defects caused by diagenetic or other processes. These are all predictable and recognizable artifacts when a tooth surface is examined at high magnifications (Teaford 1988b).

The remainder of the blind sample consisted of impressions taken by Dr. John Lukacs of teeth from Cemetery R37 at Harappa (N = 12), and of the skeletal series from Mahadaha (N = 10). The sample from Harappa consisted of antimeres of first and second molar pairs, collected from two individuals, and molar pairs from two additional individuals. The Mahadaha sample was comprised of first and second molar pairs from five individuals. Impressions taken of 11 additional molars from Harappa (Cemetery R37) became available during a later phase of this study, for a total sample of 47 teeth (Table 3.1). However, the total sample size for my qualitative microwear analysis was reduced to 35, because 12 Harappa specimens were removed as a result of replication problems. The total sample for the quantitative and comparative phase of this study was further reduced to 32, because only single antimeres (right, when available) were used in the statistical analyses.

Macroscopic and low-power microscopic preliminary examination of all whole teeth revealed that most of the molars were in good condition. The archaeological specimens appeared to be free of museum preservatives. During the excavation of Cemetery R37 at Harappa, preservative (acetone-Duco cement solution) was applied to gnathic and osteological remains that were too fragile to be excavated intact. However, preservative was intentionally not applied to any of the Harappan dental sample used in the present study (Lukacs, personal communication 1990). As previously mentioned in Chapter III, the Mahadaha burials were excavated during the late 1970s by Indian archaeologists associated with the University of Allahabad. Preservatives were undoubtedly applied to many of the Mahadaha skeletal remains. However, macroscopic examination by Dr. John Lukacs of the Mahadaha dental/gnathic collection at the University of Allahabad did not reveal the presence of preservatives (Lukacs, personal communication 1990).

Casting

Collection of Negative Impressions

Cleaning and Preliminary Examination of Original Specimens

Cleaning of the Harappa and Mahadaha tooth specimens in the field was nominal, consisting of careful removal of dirt with a soft brush and forced air from a manually-operated air bulb (Lukacs, personal communication 1990). The remainder of the dental sample was cleaned in the laboratory according to procedures outlined below. At the beginning of the research program, I experimented with ultrasound to clean whole teeth. Several of the archaeological specimens were immersed in a beaker of 95% ethanol and/or an alcohol-soap solution, and submitted to 1-3 minutes of ultrasound cleaning. However, the fragile nature of some of the specimens, especially those which exhibited postmortem damage, resulted in breakage and sluffing of pieces of enamel from the surfaces of the teeth. Acetone was occasionally found to be an unsatisfactory cleaning solvent, due to the fragility of some of the teeth and because acetone would have softened or dissolved the glue used to consolidate loose alveolar matrix of several of the specimens. Although acetone and other cleaning solvents have been used in some studies (e.g., Bullington 1988; Grine 1986; Puech et al. 1989; Solounias et al. 1988) to remove museum shellac from the enamel surfaces of prehistoric and fossil specimens, the lack of preservatives on specimens used in the present study negated the use of such highly caustic cleaning solvents.

The cleaning procedure used for the specimens available to the author was as follows: (1) the whole tooth was cleaned with a standard dilute solution (0.5% = 5ml/l) of liquid soap (Micro™) and 95% ethanol (1:1 H_20/ETOH); (2) the cleaning solution was gently rubbed onto the enamel surfaces with the fingers; (3) the cleaning solution was rinsed from the tooth surfaces with deionized water; (4) the tooth was then rinsed with 95%

ethanol applied with a plastic nozzle on a laboratory bottle; and (5) the tooth was dried and dusted with forced air, provided by compressed lab air or from a manually-operated air bulb. After evaporation of the ethanol, the cleaned tooth was allowed to dry for a minimum of 24 hours under ambient laboratory conditions before an impression was taken. Although on-line compressed air has been reported to carry particles of dust (Rose 1983), it was used for dusting the specimens in the present study to avoid the environmental degradation and additional expense of canned dichlorodifluoromethane. However, some very fragile teeth with roots that would pulverize in water were washed only minimally with alcohol-soap solution, but rinsed with dry ethanol and dried with forced air. A soft bristle tooth brush was also used to remove adhering soil matrix from the enamel surfaces of neolithic Mehrgarh specimens N1 and N2.

Preliminary low power optical examination of the tooth surfaces facilitated the determination of their condition, the presence of postmortem defects caused by diagenetic processes, and the identification of macroscopic wear features and other structures (Scott and Wyckoff 1949; Scott et al. 1949), as well as the morphology of the wear facets and other worn enamel surfaces.

Impression Materials Used

Many types of impression materials and casting techniques have been recommended for production of dental replicas for the use in the SEM (Pameijer 1978, 1979; Pameijer and Stallard 1972a, 1972b; Rose 1983; Scott 1982; Teaford and Oyen 1989a; Waters and Savage 1971). The selection of impression materials used in this study evolved over time as casting methods were perfected and in concert with several types of epoxy resins adopted for casting the positive replicas.

The three types of impression materials I used were: (1) RTV 3110™ silicone rubber, a low-viscosity cold-curing impression material manufactured by the Dow Corning

Corporation; (2) Express Regular-Set™, a low-viscosity vinyl polysiloxane impression material manufactured by the 3-M Corporation; and (3) Xantopren Blue, a condensation-curing silicone material manufactured by Unitek Corporation. Express and other addition curing elastomers flow easily, have a short setup time, are more stable than the silicone materials, and replicate extremely small features while producing few defective casts. The RTV provided adequate replicability of microscopic features with minimal shrinkage of the mold over time, but its tendency to produce casting defects led me to discontinue using it midway through the study. However, RTV impressions made in the field from some of the Harappan teeth (H87 specimens) were used to cast the positive replicas, because of the lack of opportunity to collect new impressions. These replicas were reserved for studies of tooth attrition only, or for macroscopic examination and sketching of the specimen. Out of the 47 whole tooth specimens available, 23 were originally molded with the RTV material. Express or Xantopren Blue was used to make new impressions of 11 of the Mehrgarh teeth, but the 12 H87 Harappa teeth were not available for re-casting. A more detailed discussion of casting defects is presented in a later section.

Use of Clay Supports

When impressions were made with RTV silicone rubber, its low viscosity and long setup and cure time required the placement of the original specimen in a plasticine retainer. A 'dam' of plasticine was formed around pairs of mandibular molars that were retained within their sockets (Rose 1983). Occasionally, the impression included the second premolar or third molar. This type of impression of multiple teeth was collected for the Harappa specimens during the 1987 field season. However, care was taken to prevent the plasticine from coming in contact with the teeth, because it is an oily and messy material that can easily contaminate enamel surfaces (Bullington 1988).

When taking an RTV impression of an isolated whole tooth, a lump of plasticine

was fashioned into a cone or mound and used to support the specimen during the encapsulation process (Waters and Savage 1971). The specimen and its support were placed inside a 35mm film canister, which acted as a form for the retention of the silicone material while it cured. This technique was initially used to collect impressions of many of the Mehrgarh (MR2 and MR3) samples. Recently, a refinement of this technique has been suggested by Bullington (1988).

Mixing and Pouring Elastomer

The RTV and Xantopren base and catalyst were mixed in clean containers, and vigorous stirring was avoided in order to minimize the introduction of air into the mixed compound (Rose 1983). Early in my project, experimentation in the Department of Geological Sciences at Oregon showed that the newly mixed RTV material could be degassed under vacuum, after which the material could then be applied to the tooth. However, this method was impractical under the field conditions at Harappa and with laboratory facilities available to me in the Department of Anthropology at Oregon.

The Express material was applied with an auto-mix system, in which the dispensing spout attached to the two cartridges of material automatically mixes the base and catalyst. The syringeable viscosity material was then applied carefully, but quickly, to the surface of the specimen (s) by pushing the material ahead of the dispenser tip (much as one would apply a bead of caulking compound to a window frame), to prevent the formation of gas bubbles. Care was taken to ensure that the impression material was allowed to flow into sulci and crenulations on the occlusal surface of the tooth.

Curing Conditions

The impression materials were allowed to cure at room temperature for at least 24 hours before the mold was disturbed, although this is only necessary with the RTV material

(Teaford, personal communication 1991). However, the high ambient temperatures and humidity under which the H87 Harappa specimens were replicated probably caused the RTV material to cure at a faster rate. This more rapid rate of polymerization may have allowed insufficient time for trapped air bubbles to dissipate before the material fully cured. Frequently, pits or craters ('bubble defects') were formed on the inner surfaces of the RTV impressions as a result of entrapment of air or gasses, formed during the polymerization process, at the interface between the original tooth and the rubber impression as the material polymerized. There is also a possibility, although slight, that such casting defects were caused by evaporation of gas from the cleaning liquids into the uncured mold, due to insufficient time for the teeth to dry before the impressions were taken. The repercussions for positive replicas cast from these defective molds are discussed below.

Occasionally, a mold would tear during removal of a tooth. When this occurred, the damage was easily repaired by the application of a small amount of uncured impression material. The completed molds were set aside for several additional days to allow a complete cure to take place and so that the material could degas. All molds made in the Eugene lab were used to produce replicas within one week of their production, to minimize the amount of shrinkage that occurs as a natural part of the curing process for condensation-cure silicones.

Casting Positive Epoxy Replicas

Casting Process and Curing Conditions

Prior to casting the positive epoxy replicas, the negative impressions were ultrasonically cleaned for 5 to 10 minutes in an alcohol/soap solution (5ml of Micro liquid soap, 390 ml ethanol, and 600 ml deionized water). The impressions were then rinsed with deionized water, followed by 95% ethanol. Impressions were dried with on-line compressed air.

Three types of epoxy resin material were used in this study to cast positive replicas from the molds: (1) FOUR-to-ONE™ epoxy resin manufactured by TAP Plastics; (2) Epo-Tek 301™, a clear low-viscosity, cold-curing epoxy resin manufactured by Epoxy Technology; and (3) Araldite 956 with 295 hardener, also a low-viscosity, cold-curing epoxy resin manufactured by Ciba-Geigy Corporation. The proper ratios of resin and catalyst were determined by weight, and mixing of the catalyst and resin was done carefully to avoid entrapment of air in the mixture. The mixed epoxy was subsequently introduced into the mold by syringe or with a capillary rod, to further minimize the introduction of air bubbles to the mixture (Rose 1983). The Araldite replicas, made by Dr. Mark Teaford, were cast using techniques described previously (Teaford and Walker 1984; Teaford and Oyen 1989d).

The filled mold was subsequently placed in a centrifuge for three to seven minutes at high speed, to dissipate entrapped air and to drive the epoxy mixture into minute recesses of the mold. When a twin mold was too large for the specimen holder of the high-speed centrifuge, it was placed inside a 35mm film canister suspended in a custom-made wire basket, and spun for a minimum of three minutes at moderate speed with a hand centrifuge.

The epoxy replicas, whether cast from Epo-Tek 301, Araldite, or TAP 'Four-to-One' resins, were allowed to cure at room temperature for at least 24 hours before the replicas were removed from their molds. Once out of the mold and prior to mounting, the replica was allowed to cure for an additional 24 to 48 hours at room temperature, to allow all surfaces to harden and any residual solvents to evaporate. Once fully cured, the replica was handled sparingly and then only at the ends (mesial and buccal surfaces). Any contact by the fingers or other objects with the occlusal surfaces of the replica was avoided. In addition, handling of a fully cleaned replica, prior to mounting, was done with plastic-tipped tweezers to avoid transferring oils from the hands to the surface of the replica.

Casting Artifacts

Various types of artifacts can be formed in the surface of the epoxy replica during the curing process. The appearance and formation of such casting defects have been discussed previously by Gordon (1984a) and Teaford (1988b). Some of these defects have the appearance of small, smooth-sided pits or craters, which often protrude more deeply into the replica surface than microwear features (pits or gouges). Such casting artifacts are occasionally formed by gas bubbles trapped between the surface of the curing epoxy and the rubber mold, due to degassing of the latter (i.e., degassing artifacts). The pits or craters may be of different shape depending on the how rapidly gas is emitted from the mold during its contact with the curing epoxy. In fact, these and other defects have been referred to as 'bubble artifacts' (Gordon 1984a), because of their appearance and method of formation. Such casting artifacts were much more prevalent on replicas made from the TAP Plastics resin in combination with molds (impressions) of Dupont RTV silicone rubber. This was not a problem because the Tapox replicas were only used for low power optical examination.

Spherical artifacts occasionally formed on the surface of positive replicas that had been cast from molds possessing degassing artifacts (i.e., negative impressions of gas bubbles). Essentially, the spherical artifacts on the surface of a cured replica are positive casts (filling defects) of the pits or craters that had formed during the curing process of the mold itself. In most cases, small positive bubbles or beads are formed on exposed dentine surfaces (Figure 4.1). These artifacts are the positive replicas of bubbles of gas evaporating into the uncured mold from openings of dentin tubules.

An exothermic reaction occasionally occurs between the impression and the epoxy replicating materials. This results in depolymerization (degassing) of the silicone rubber impression material while the epoxy casting material is curing (i.e., evaporation of solvents into the epoxy). Subsequently, very tiny pits or craters (negative impressions of gas

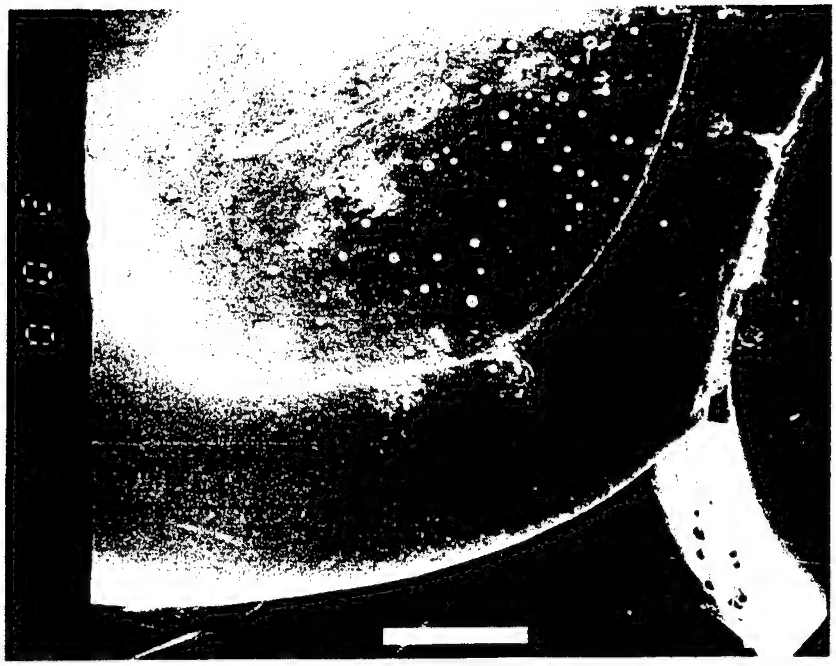

Figure 4.1. Low Magnification (20x) Micrograph (X1-4001) of Positive Filling Artifacts on Replica of Mahadaha Molar Specimen MDH-15-X1 Occlusal Surface.

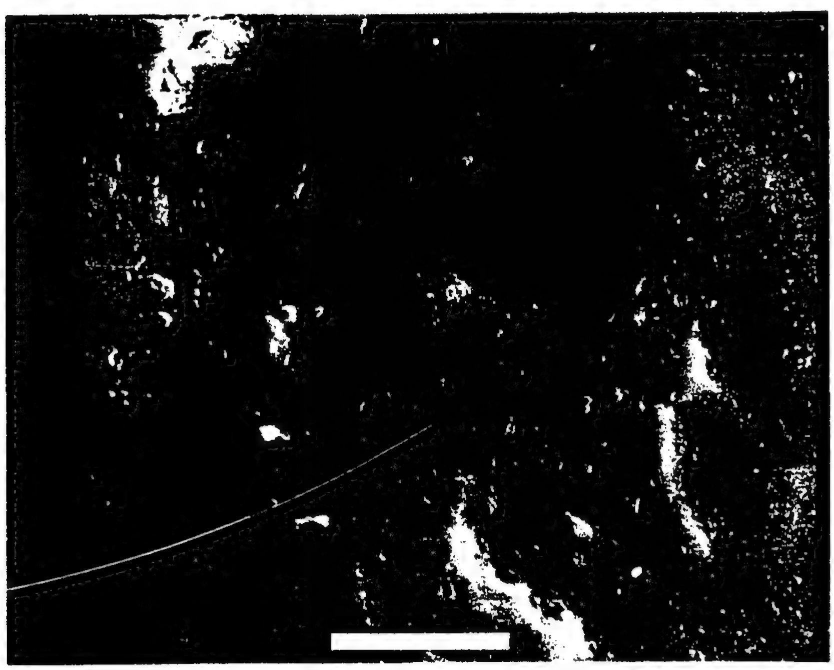

Figure 4.2. High Magnification (500x) Micrograph (K2-2113) of Degassing Pit Artifacts on Facet 1 Surface of Harappa Molar Specimen H87-60-46a-32-K2.

bubbles) are formed on the surface of the epoxy replica. The problem was especially severe when the TAP Plastics epoxy was combined with a mold made of RTV silicone rubber. Apparently, the large amount of heat generated by the curing epoxy within the confined space of the mold cavity produced depolymerization of the RTV rubber. This combination of molding materials was used to produce the original replicas of the Harappa (H87) teeth, as well as most of the tooth specimens from both Mehrgarh sites (MR2, MR3). The problem was less severe when the Epo-Tek epoxy was used with RTV molds. However, the problem was almost nonexistent for replicas that were cast from Epo-Tek epoxy in combination with molds made of Express, or with the combination of Xantopren molds and Araldite epoxy.

Ultimately, the resulting artifacts are quite tiny (2 µm in diameter or less), although the positive filling defects can be considerably larger. Such very tiny pits characteristic of degassing crater artifacts are illustrated in a 500x micrograph of Harappa specimen H87-60 (Figure 4.2). Both types of artifact are troublesome to accurate dental microwear analysis of tooth replicas: the positives because they contribute to 'charging' in the SEM, and the degassing pits because they obscure fine detail on the surface of the replica.

For example, micrographs from the H87 specimens uniformly exhibited less detail, including fewer fine scratches, than micrographs from H88 replicas produced with the vinyl polysiloxane molds. Therefore, total feature counts, even when the unmeasured count category (explained in a later section) was added, were low for the H87 sample relative to the H88 sample. These low densities for fine features were caused by the occurrence of bubble artifacts.

Unfortunately, their presence was not realized until the original SEM analyses and all data collection and analysis of specimens in the original sample were completed, and after review of the data by Dr. Mark Teaford (personal communication 1990). The tiny degassing pits on the H87 replicas (e.g., H87-71 E1/E2, H87-85 G1/G2) and Mehrgarh

(MR2, MR3) replicas would not necessarily cause a problem when comparing microwear dimensions with specimen fields from H88 (Harappa) or other groups. Comparative problems could be avoided by sorting scratches and pits by width, and using only those features larger than a set value for statistical comparisons with other samples such as Mahadaha or chalcolithic Mehrgarh. However, the density and width of fine scratches are important variables in this study, the measurement of which would be suspect on micrographs from defective replicas. Consequently, it was decided at the end of the first phase of this study to discard the defective replicas. As previously stated, this resulted in the complete removal from the sample of the H87 specimens (n = 12) because the original teeth were unavailable. However, it was possible to produce new Xantopren impressions and Araldite replicas from 10 of the Mehrgarh teeth, from which defective replicas had originally been made. Later phases of this study used these new Mehrgarh replicas and Epo-Tek replicas of Harappa teeth made from Express molds collected during the 1988 field season.

Preparation of Replicas for Optical and SEM Analysis

After removal of the replica from its mold, an initial examination was performed at low power with a binocular microscope to determine the accuracy with which morphological features had been replicated, and the presence of any casting defects or contamination of the replica by particles of soil or sand. For example, impressions occasionally picked up dirt particles that had been adhering to the original surface of the tooth. Consequently, these same particles were sometimes plucked from the impression by the replica and remained adhered to the epoxy surface. In such cases, the contaminated replica was used for macroscopic examination only, and a duplicate replica was produced for use with the SEM. However, the dirt particles themselves might not pose a problem to the analysis, providing they do not hinder pulling a vacuum on the SEM (Teaford, personal

communication 1991).

After removal from the mold, the base of a replica often possesses a concave surface. To provide an adequate surface for adhesion to a glass mount, the base of each replica was sanded flat with 120 or 320 grit wet-or-dry sandpaper. Pieces of excess epoxy clinging to the replica were also trimmed from the base of the replica with a pair of diagonal cutters. Replicas were ultrasonically cleaned for 3 to 5 minutes in an alcohol/soap solution to ensure the removal of any solvents remaining on the surface. Replicas were then rinsed with deionized water, followed by 95% ethanol, and dried with on-line compressed air. After cleaning, replicas were handled with plastic-tipped tweezers prior to mounting.

Most replicas were mounted to a 1-inch diameter glass slide to facilitate the optical analysis. Prior to mounting, the glass slide was cleaned with alcohol/soap solution and rinsed with ethanol, and air dried. Mounting was accomplished with Buehler® thermoplastic cement applied to the slide after it was heated on a hotplate. After placing the replica on the melted adhesive, the slide was removed from the heat source and the adhesive was allowed to cool and harden. A 'tick' mark (reference mark) was etched into the slide near its perimeter and oriented on line parallel to a sagittal plane dissecting the buccal pit vertically. In the case of a dual mount where the M_1 and M_2 are replicated together, the 'tick' mark was placed in a plane running vertically between the two teeth. This mark was used for reference purposes during optical analysis. During later phases of the study, the new Mehrgarh replicas were mounted directly to aluminum stubs. Mounted specimens were placed in plastic boxes or aluminum sample pans and stored in a dessicator cabinet, prior to conducting the optical analysis and before and after the SEM analyses.

Optical Analysis of Wear Facets

Introduction

When a specimen is placed into the evacuated specimen chamber of the SEM, the orientation of the surface (e.g., facet) to be examined, relative to the primary electron beam and the secondary electron detector (i.e., the instrument stage geometry), becomes important in quantitative and comparative analyses of microwear features (Gordon 1984a, 1984d, 1988a). For example, some linear features oriented parallel to the detector are foreshortened when the specimen stage is tilted at strong angles toward the detector. Consequently, the dimensions of the feature represented as an image on the video display or micrograph may not represent reality. This is not necessarily a problem if the SEM images of all specimen facet surfaces are produced with similar orientations. Therefore, I rigorously standardized the specimen orientation in the instrument chamber, with regard to the relative angle of inclination and rotational angle of the facet surface on the tooth crown. In this way, many of the variables associated with the SEM imaging process were held relatively constant, and feature variation between micrographs is due to functional rather than methodological causes. Knowledge of these angular parameters for each tooth specimen facilitates initially orientating the facet surface so that it is normal to the primary electron beam and the direction of tilt of the instrument stage. In this way, the SEM analysis session can begin with each specimen in a standard (normal) position, from which the tilt angle of the specimen relative to the electron beam can be gradually increased to improve the visual brightness and contrast. My section "Theoretical and Practical Application" of SEM analysis discusses these issues further.

With substantial experience on the SEM, it is possible to determine visually when the surface of a specimen is in a normal position, by the appearance of a darkened field with lowered contrast, compared to the same field of view with tilt angles away from

normal. However, such a technique is not capable of holding as many methodological variables constant as the protocol described below.

Equipment and Technique

A specialized technique was devised with the assistance of Mr. Michael Shaffer, research assistant with the University of Oregon Department of Geological Sciences, to optically map and examine wear facets on tooth replicas. The technique uses a specially modified universal microscope stage to measure the relative angle of wear facets, by measuring the angle of incidence of the light beam from an illuminating lamp with the facet surface. A Leitz rotatable microscope stage was modified for this phase of the study by mounting the stage to a block of wood, in which a 4-inch diameter hole had been sawn. The stage was fastened over the hole to allow it to be rotated at a high incident angle relative to the horizontal plane. A Bausch and Lomb binocular microscope equipped with 15x objective lenses and fixed illumination was used for the analysis. To minimize variability between mapping sessions, the microscope was carefully positioned so that the focal plane was parallel to the base of the rotatable stage, and with the plane of tilt of the stage normal to the axis of the light beam from the illuminating lamp.

Angle of Rotation of Specimen

As part of my standardized protocol, the relative position of the wear facets on a specimen were recorded with light microscopy, to facilitate the placement of the facet surface at an angle normal to the axis of the secondary electron detector, and to help locate the facet(s) under the relatively narrower field of view produced at high magnification. The glass slide, on which the specimen was mounted, was temporarily fastened to the stage of the binocular microscope using double stick adhesive tape. Initially, the mount was positioned with the inscribed reference mark aligned with the 180 degree mark on the stage,

and with the buccal surface of the tooth facing the microscope illumination lamp.

When Phase II facets were analyzed, the mounted specimen was rotated 180 degrees from this initial position so that the Phase II facet surface also faced the illumination lamp. Under 10-15x magnification, measurement of the horizontal angle of rotation of the moveable stage was accomplished by rotating the specimen until the facet of interest was centered in the field of view. Then the specimen was rotated slowly in a back-and-forth fashion until the reflection of the light beam from the surface of the facet was approximately evenly distributed and at the center of the facet. The angle of rotation with the specimen in this position was read from the horizontal bezel. The average measurement taken from two trials was recorded, and is shown for each of the specimens in Table 4.1.

Because the horizontal angle of rotation on the JEOL microscope stage is calibrated in parts per thousand, a mathematical equation was used to convert the angle of rotation (degrees) calculated from the optical microscope to one useable with the electron microscope.

$$\left[\frac{(\text{Degree of Rotation} - 180^\circ)}{360^\circ} \times 1000\right] + 625$$

The equation also includes a constant of 625 parts per thousand, because the electron detector of the instrument is positioned at a 45 degree angle from the horizontal plane of movement (X-axis) of the instrument stage. The calculated SEM stage rotation angle for the Phase I and II facets of all specimens is shown in Table 4.2. In practice, a 1 degree rotation angle from the optical microscope converts to approximately a 3 parts per thousand rotation angle for the SEM.

Angle of Inclination of Facet (s)

The standardized protocol employed for this study requires the plane of the facet surface to be initially oriented normal to the axis of the electron beam. To achieve this with

Table 4.1. Angles of Rotation and Inclination of Facet Surface Determined from Optical Analysis of Molar Specimen

Specimen Number	Facet Number	Rotation Angle	Facet Tilt Angle	Correction Factor	Tilt Angle + Correction Factor	Relative Angle of Facet
A1	1	201	341	-12	329	31
	2	96/108	346	-12	334	26
	6	178	357	-12	345	15
A2	1	165	341	-12	329	31
	2	128	344	-12	332	28
	6	151	345	-12	333	27
B1	1	182	350	-11	339	21
	2	139	332	-11	321	39
	3	173	363	-11	352	8
	4	187	335	-11	324	36
B2	1	190	355	-11	344	16
	2	no facet				
	3	40	317	-11	306	54
	4	no facet				
C1	1	147	359.5	-11	348.5	11.5
	2	219	335	-11	324	36
	6	214 (v)	347.5	-11	336.5	23.5
C2	1	138	355.5 (v)	-11	344.5	15.5
	2	241	317.5 (v)	-11	306.5	53.5
	4	138	355.5 (v)	-11	344.5	15.5
	6	212	333	-11	322	38
D1	1	192	324 (v)	-11	313	47
	2	164	332	-11	321	39
	3	213	364	-11	353	7
D2	1	176	350	-11	339	21
	2	151	346	-11	335	25
	3	350	349	-11	338	22
E1	1	207	324	-11	313	47
	2	268	327	-11	316	44
	3	230	357	-11	346	14

Table 4.1. (Continued).

Specimen Number	Facet Number	Rotation Angle	Facet Tilt Angle	Correction Factor	Tilt Angle + Correction Factor	Relative Angle of Facet
E2	1	206	347	-11	336	24
	2	145	343	-11	332	28
	3	180	369	-11	358	2
	4	198	326	-11	315	45
F	1	157	334	-11	323	37
	2	191	335	-11	324	36
	3	10	341	-11	330	30
G1	1	162	336	-11	325	35
	2	215	355	-11	344	16
	3	50	353	-11	342	18
G2	1	173	351	-11	340	20
	2	222	335	-11	324	36
	3	348	328	-11	317	43
H1	1	155	331.5	-11	320.5	39.5
	2	193 (v)	344 (v)	-11	333	27
	6	191	355°	-11	329	31
H2	1	174	333	-12	321	39
	2	210	328 (V)	-12	316	44
	6	175	333	-12	321	39
I1	1	176	339	-12	327	33
	2	133 (v)	349.5 (v)	-12	337.5	22.5
	6	169	345	-12	333	27
I2	1	205	345	-11	334	26
	2	159	343 (v)	-11	332	28
	4	125	347.5	-11	336.5	23.5
	6	155 (v)	343 (v)	-11	332	28
J1	1	174	331	-11	320	40
	2	200 (v)	328 (v)	-11	317	43
	6	151	337	-11	326	34

Table 4.1. (Continued).

Specimen Number	Facet Number	Rotation Angle	Facet Tilt Angle	Correction Factor	Tilt Angle + Correction Factor	Relative Angle of Facet
J2	1	172/204	342/338	-11	331/327	29/33
	2	238	320.5	-11	309.5	50.5
	6	149	325	-11	314	46
K1	1	192	354	-11	343	17
	2	230	319	-11	308	52
	3	350	357	-11	346	14
K2	1	147	340	-11	329	31
	2	227	334	-11	323	37
	3	20	324	-11	313	47
L1	1	193	372.5	-12.5	360	0
	2	144	353 (v)	-12.5	340.5	19.5
	3	327	364	-12.5	351.5	8.5
	4	187	349	-12.5	336.5	23.5
L2	1	190	354	-12.5	341.5	18.5
	2	106	336	-12.5	323.5	36.5
	3	348	336.5	-12.5	324	36
M	1	174	346/336	-11	335/325	25/35
	2	216	331	-11	320	40
	6	179	338.5	-11	327.5	32.5
	4*	193	336	-11	325	35
N1	1	170	342	-12	330	30
	2	233	334	-12	322	38
	3	2	3	-12	351	9
N2	1	144	320.5	-11	309.5	50.5
	2	206/216	326/330	-11	315/319	45/41
	3	199	335	-11	324	36
U1	1	190	330	-12	318	42
	2	230	347.5	-12	335.5	24.5
	3	18	360	-12	348	12

Table 4.1. (Continued).

Specimen Number	Facet Number	Rotation Angle	Facet Tilt Angle	Correction Factor	Tilt Angle + Correction Factor	Relative Angle of Facet
U2	1	185	345	-12	333	27
	2	232	339	-12	327	33
	3	358	365	-12	353	7
V1	1	162	354	-12	342	18
	2	231 (v)	342 (v)	-12	330	30
	3	no facet				
V2	1	181	356.5	-12	344.5	15.5
	2	247 (v)	340 (v)	-12	328	32
	3	11	349	-12	337	23
W1	1	224 (v)	353	-12	341	19
	2	123	357	-12	345	15
	3	328	360.5	-12	348.5	11.5
W2	1	216	354.5	-12	342.5	17.5
	2	95	350	-12	338	22
	3	31	352	-12	340	20
X1	1	134 (v)	355.5	-12	343.5	16.5
	2	227 (v)	365	-12	353	7
	3	2	357	-12	345	15
X2	1	144	350	-12	338	22
	2	213	355.5	-12	343.5	16.5
	3	348 (v)	365	-12	353	7
Y1	1	185	358 (v)	-12	346	14
	2	226	361	-12	349	11
	3	357 (v)	355	-12	343	17
Y2	1	233 (v)	353	-12	341	19
	2	190 (v)	366	-12	354	6
	3	no facet				
AA1	1	207	344	-12	332	28
	2	no facet				
	6	195	359	-12	347	13

Table 4.1. (Continued).

Specimen Number	Facet Number	Rotation Angle	Facet Tilt Angle	Correction Factor	Tilt Angle + Correction Factor	Relative Angle of Facet
AA2	1	201	353	-12	341	19
	2	225	348	-12	336	24
	6	220	352	-12	340	20
BB1	1	171	358	-12	346	14
	2	185	346 (v)	-12	334	26
	6	198	357 (v)	-12	345	15
BB2	1	138	362.5	-12	350.5	9.5
	2	180	355	-12	343	17
	6	198	362	-12	350	10
CC1	1	166	360 (v)	-12	348	12
	2	230	355	-12	343	17
	6	178	363	-12	351	9
CC2	1	170	358.5	-12	346.5	13.5
	2	202	358.5	-12	346.5	13.5
	6	151	364 (v)	-12	352	8
DD1	1	195 (v)	358.5	-11	347.5	12.5
	2	122	348.5	-11	337.5	22.5
	6	163 (v)	361	-11	350	10
EE1	1	184	341	-12	329	31
	2	damaged				
	6	184	339	-12	327	33
EE2	1	175	342	-12	330	30
	2	197	341	-12	329	31
	6	189	342.5	-12	330.5	29.5
FF1	1	175	334.5	-12	322.5	37.5
	2	152 (v)	331 (v)	-12	319	41
	6	175	334 (v)	-12	322	38
FF2	1	172	333 (v)	-12	321	39
	2	156 (v)	337 (v)	-12	325	35
	6	171	334 (v)	-12	322	38

certainty, the relative angle of inclination (tilt angle) of the facet surface on each molar was analyzed. The shape of most wear facets is rarely planar, with many taking a convex or concave shape that often varies across the facet surface. In practice, this variable shape occasionally produced some difficulty in obtaining an accurate and replicable determination of the tilt angle. However, the small field of view (0.02-0.03mm^2) at 500x effectively allows the assumption of a planar surface, when the facet surface is imaged with the electron microscope. In addition, a worn molar possessing only a narrow platform of occlusal enamel, rather than a neatly defined wear facet, was always more difficult to analyze both for the rotation angle as well as the tilt angle. In such cases, the angles were recorded as variable, so that adjustments in either angle of the SEM stage could be made during SEM analysis.

Prior to the actual analysis of facet inclination, a correction factor was determined corresponding to the incident angle of the light beam as it passes through a plane parallel to the plane of the objective lenses of the microscope. In practice, this angle rarely varied, but remained within the range of 11-12 degrees, because the illumination lamp could be fixed in position on the microscope. However, this angle was always checked whenever beginning an optical analysis session, to ensure that the interspecimen variability for measured relative tilt angle was low.

The tilt angle of a facet was analyzed in conjunction with the optical analysis of the rotation angle. The moveable stage was rotated through a range of vertical angles until the reflection of the light beam from the surface of the facet was approximately centered on the facet. As before, two trials were conducted and the average of the two measured angles recorded for the Phase I and II facets of each specimen (Table 4.1). The measured angle of light reflectance from the optical microscope was converted for use with the SEM stage as follows. The actual relative angle of the facet was calculated by subtracting the previously determined correction factor from the measured tilt angle, and then subtracting this figure

from 360 degrees. The relative angle calculated for facets from all specimens is illustrated in Table 4.2.

Recognition and Naming of Wear Facets

As discussed in Chapter II, except for work by Maier and Schneck (1981, 1982), a standardized wear facet nomenclature has not been developed for human dentitions. Such a system has a long history of development for fossil and modern non-human primates and other mammals (Butler 1952; Hiiemae and Kay 1973; Janis 1984; Kay and Hiiemae 1974; Kay 1977; Mills 1967). For this research, a standardized facet nomenclature was adapted from Kay (1977) and Maier and Schneck (1981, 1982) for use in the recognition and standard description of Phase I and II facets on the protoconid (cusp 1) of first and second mandibular molars.

Facets 1 and 2 are Phase I facets located on the protoconid of mandibular molars. The former facet is adjacent to the buccal pit and/or buccal groove, whereas facet 2 is located mesial to facet 1 and usually at the mesiobuccal corner of the occlusal surface. As facet locations are normally defined only for slightly-worn teeth, a homologous position for the SEM field was chosen in the case of specimens without actual facets (e.g., an unerupted tooth with no occlusal surface wear or an extremely worn tooth, in which only a rim of enamel remains). Facets 1 and 2 are equivalent in position and nomenclature to those shown for Homo sapiens in the standardized facet nomenclature developed by Maier and Schneck (1981, 1982). These facets are also homologous to Phase I wear facets 1 and 2 described by Kay (1977) for Macaca mulatta.

Occasionally, two additional Phase I facets (facets 4 and 5) were mapped on cusp 1 of some specimens. These are buccal-facing facets and usually adjacent to facet 1. Generally, facet 4 was located cervically to facet 1, nearly on the buccal surface of the tooth, and is delineated from facet 1 by a noticeable change in the orientation and angulation

Table 4.2. Facet Rotation and Inclination Angles Adjusted for SEM Stage

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
A1	0117N	683	31	31
	0119N	683	31	56
	0127N	392/425	26	51
	0129N	392/425	26	51
	0167N	620	15	15
	0169N	620	15	40
A2	0217T	583	31	31
	0219T	583	31	56
	0227T	481	28	28
	0229T	481	28	53
	0267T	544	27	27
	0269T	544	27	52
B1	0311	756	21	21
	0312	756	21	21
	0314	756	21	46
	0321	636	39	39
	0322	636	39	39
	0341	769	36	36
	0342	769	36	36
B2	0411	778	16	16
	0412	778	16	16
	0413	778	16	41
	0431	361	54	54
	0432	361	54	54
	0435	778	16	41
C1	0517T	533	11.5	26.5*
	0519T	533	11.5	51.5*
	0527T	733	36	36
	0529T	733	36	60
	0567T	719 (v)	23.5	23.5
	0569T	719 (v)	23.5	48.5
C2	0617N	508	15.5 (v)	15.5
	0619N	508	15.5 (v)	40.5
	0627N	794	53.5 (v)	53.5

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
C2	0629N	794	53.5 (v)	61
	0667N	714	38	38
	0669N	714	38	61
	0647N	508	15.5 (v)	15.5
	0649N	508	15.5 (v)	40.5
D1	0711	783	47 (v)	47
	0712	783	47 (v)	47
	0713	783	47 (v)	57
	0714	783	47 (v)	57
	0721	706	39	39
	0722	706	39	39
	0723	706	39	49
	0724	706	39	49
	0731	842	7	7
	0732	842	7	7
D2	0811	739	21	21
	0812	739	21	21
	0813	739	21	36
	0814	739	21	36
	0821	669	25	25
	0822	669	25	25
	0823	669	25	35
	0831	97	22	22
	0833	97	22	32
E1	0911	825	47	47
	0912	825	47	47
	0913	825	47	61
	0917**	825	47	61
	0921	717	44	44
	0922	717	44	44
E2	1011	822	24	24
	1012	822	24	24
	1013	822	24	49
	1041	800	45	45
	1042	800	45	45

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
F	1111	686	37	37
	1112	686	37	37
	1121	781	36	36
	1122	781	36	36
	1123	781	36	51
	1124	781	36	51
	1131	278	30	30
	1132	278	30	30
G1	1211	700	35	35
	1212	700	35	35
	1215	700	35	60
	1221	847	16	16
	1222	847	16	16
	1223	847	16	31
	1231	389	18	18
	1232	389	18	18
G2	1311	731	20	20
	1312	731	20	20
	1313	731	20	30
	1321**	867	36	46
	1322**	867	36	46
	1331	92	43	43
	1332	92	43	43
H1	1417N	556	39.5	39.5
	1419N	556	39.5	61
	1427N	661	27	27
	1429N	661	27	52
	1467N	656	31	31
	1469N	656	31	56
H2	1517T	608	39	39
	1519T	608	39	60
	1527T	708	44	44
	1529T	708	44	60
	1567T	611	39	39
	1569T	611	39	60

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
I1	1617T	614	33	33
	1619T	614	33	58
	1627T	494	22.5	22.5
	1629T	494	22.5	47.5
	1667T	594	27	27
	1669T	594	27	52
I2	1717T	694	26	26
	1719T	694	26	51
	1727T	567	28	28
	1729T	567	28	53
	1747T	472	23.5	23.5
	1749T	472	23.5	48.5
	1767T	556	28	28
	1769T	556	28	53
J1	1817T	608	40	40
	1819T	608	40	60
	1827T	681	43	43
	1829T	681	43	61
	1867T	544	34	34
	1869T	544	34	59
J2	1917T	603/692	29/33	29/33
	1919T	603/692	29/33	54/58
	1927T	786	50.5	50.5
	1929T	786	50.5	61
	1967T	539	46	46
	1969T	539	46	61
K1	2011	783	17	17
	2012	783	17	17
	2013	783	17	27
	2014	783	17	27
	2021	889	52	52
	2022	889	52	52
	2023	889	52	60
	2031	97	14	14
	2033	97	14	24

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
K2	2111	658	31	31
	2112	658	31	31
	2113	658	31	46
	2114	658	31	46
	2121	881	37	37
	2122	881	37	37
	2123	881	37	47
	2124	881	37	47
	2131	306	47	47
	2133	306	47	57
L1	2211	661	0	0
	2212	661	0	0
	2213	661	0	15
	2214	661	0	15
	2221	525	19.5	19.5
	2223	525	19.5	34.5
	2231	33	8.5	8.5
	2233	33	8.5	23.5
	2241	644	23.5	23.5
	2242	644	23.5	23.5
	2243	644	23.5	38.5
	2244	644	23.5	38.5
L2	2311	653	18.5	18.5
	2312	653	18.5	18.5
	2313	653	18.5	33.5
	2314	653	18.5	33.5
	2321	419	36.5	36.5
	2322	419	36.5	36.5
	2323	419	36.5	51.5
	2324	419	36.5	51.5
	2331	92	36	36
	2333	92	36	51
M	2417T	608	25/35	25/35
	2419T	608	25/35	50/60
	2427T	725	40	40

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
M	2427T	725	40	40
	2429T	725	40	61
	2467T	622	32.5	32.5
	2469T	622	32.5	57.5
	2447T**	661	35	35
	2449T**	661	35	60
N1	2511	722	30	30
	2512	722	30	30
	2513	722	30	45
	2514	722	30	45
	2521	897	38	38
	2522	897	38	38
	2523	897	38	53
	2524	897	38	53
	2531	256	9	9
	2533	256	9	24
N2	2617T	525	50.5	50.5
	2619T	525	50.5	61.5
	2627T	625/725	45/41	45/41
	2629T	625/725	45/41	61/61
	2667T	678	36	36
	2669T	678	36	61
U1	3411	778	42	42
	3412	778	42	42
	3413	778	42	57
	3414	778	42	57
	3421	800*	24.5	24.5
	3422	800*	24.5	24.5
	3423	800*	24.5	39.5
	3424	800*	24.5	39.5
	3431	300	12	39.5
	3433	300	12	54.5
U2	3511	764	27	27
	3512	764	27	27
	3513	764	27	42

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
U2	3514	764	27	42
	3521	894	33	33
	3522	894	33	33
	3523	894	33	48
	3524	894	33	48
	3531	300	12	12
	3533	300	12	27
V1	3611	700	18	18
	3612	700	18	18
	3613	700	18	33
	3614	700	18	33
	3621	815*	30 (v)	30
	3622	815*	30 (v)	30
	3623	815*	30 (v)	45
	3624	815*	30 (v)	45
V2	3711	753	15.5	15.5
	3712	753	15.5	15.5
	3713	753	15.5	30.5
	3714	753	15.5	30.5
	3721	936 (v)	32 (v)	32
	3722	936 (v)	32 (v)	32
	3723	936 (v)	32 (v)	47
	3724	936 (v)	32 (v)	47
	3731	281	23	23
	3733	281	23	38
W1	3811	872 (v)	19	19
	3812	872 (v)	19	19
	3813	872 (v)	19	34
	3814	872 (v)	19	34
	3821	625*	15	15
	3822	625*	15	15
	3823	625*	15	30
	3824	625*	15	30
	3831	161	11.5	11.5
	3833	161	11.5	26.5

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
W2	3911	850	17.5	17.5
	3912	850	17.5	17.5
	3913	850	17.5	32.5
	3914	850	17.5	32.5
	3925**	514	22	22
	3926**	514	22	22
	3927**	514	22	37
	3928**	514	22	37
	3931	336	20	20
	3933	336	20	35
X1	4011	622 (v)	16.5	16.5
	4012	622 (v)	16.5	16.5
	4013	622 (v)	16.5	31.5
	4014	622 (v)	16.5	31.5
	4021	881 (v)	7	7
	4022	881 (v)	7	7
	4023	881 (v)	7	22
	4024	881 (v)	7	22
	4031	256	15	15
	4033	256	15	30
X2	4111	650	22	22
	4112	650	22	22
	4113	650	22	37
	4114	650	22	37
	4121	842	16.5	16.5
	4122	842	16.5	16.5
	4123	842	16.5	31.5
	4124	842	16.5	31.5
	4131	217 (v)	7	7
	4133	217 (v)	7	22
Y1	4311	764	14 (v)	14
	4312	764	14 (v)	14
	4313	764	14 (v)	29
	4314	764	14 (v)	29
	4321	838*	11	11

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
Y1	4322	838*	11	11
	4323	838*	11	26
	4324	838*	11	26
	4331	242 (v)	17	17
	4333	242 (v)	17	32
Y2	4411	897 (v)	19	19
	4412	897 (v)	19	19
	4413	897 (v)	19	34
	4414	897 (v)	19	34
	4421	778 (v)	6	6
	4422	778 (v)	6	6
	4423	778 (v)	6	21
	4424	778 (v)	6	21
AA1	4511	700	28	28
	4512	700	28	28
	4513	700	28	43
	4514	700	28	43
	4515	700	28	53
	4561	667	13	13
	4562	667	13	13
	4563	667	13	28
	4564	667	13	28
AA2	4611	683	19	19
	4612	683	19	19
	4613	683	19	34
	4614	683	19	34
	4615	683	19	44
	4621	750	24	24
	4623	750	24	39
	4661	736	20	20
	4663	736	20	35
	4665	736	20	45
BB1	4711	600	14	14
	4713	600	14	29
	4715	600	14	39
	4716	600	14	39

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
BB1	4721	639	26	26
	4723	639	26	41
	4761	675	15	15
	4763	675	15	30
BB2	508	508	9.5	9.5
	4813	508	9.5	24.5
	4815	508	9.5	34.5
	4816	508	9.5	34.5
	4821	625	17	17
	4823	625	17	32
	4861	675	10	10
	4863	675	10	25
CC1	4911	586	12 (v)	12
	4913	586	12 (v)	27
	4915	586	12 (v)	37
	4916	586	12 (v)	37
	4921	764	17	17
	4923	764	17	32
	4961	619	9	9
	4963	619	9	24
CC2	5011	597	13.5	13.5
	5013	597	13.5	28.5
	5015	597	13.5	38.5
	5016	597	13.5	38.5
	5021	686	13.5	13.5
	5023	686	13.5	28.5
	5061	544	8 (v)	8
	5063	544	8 (v)	23
DD1	5111	667	12.5	12.5
	5112	667	12.5	12.5
	5115	667	12.5	37.5
	5116	667	12.5	37.5
	5121	464	22.5	22.5
	5122	464	22.5	22.5
	5125	464	22.5	47.5

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
DD1	5126	464	22.5	47.5
	5161	578	10	10
	5163	578	10	35
EE1	5211	636	31	31
	5213	363	31	46
	5215	636	31	56
	5216	636	31	56
	5261	636	33	33
	5263	636	33	48
EE2	5311	611	30	30
	5313	611	30	45
	5315	611	30	55
	5316	611	30	55
	5321	672	31	31
	5323	672	31	46
	5361	650	29.5	29.5
	5363	650	29.5	44.5
FF1	5411	611	37.5	37.5
	5412	611	37.5	37.5
	5413	611	37.5	52.5
	5415	611	37.5	60
	5416	611	37.5	60
	5421	547 (v)	41 (v)	41
	5423	547 (v)	41 (v)	56
	5461	611	38 (v)	38
	5463	611	38 (v)	53

Table 4.2. (Continued).

Specimen Number	Micrograph Number	Rotation Angle of SEM Stage	Tilt Angle of SEM Stage for Normality	Tilt Angle of Stage for SEM Analysis
FF2	5511	603	39	39
	5513	603	39	54
	5515	603	39	60
	5516	603	39	60
	5517	603	39	39
	5519	603	39	60
	5521	558 (v)	35 (v)	35
	5523	558 (v)	35 (v)	50
	5561	600	38 (v)	38
	5563	600	38 (v)	53

Note: Rotation angle is in parts per thousand; all other angles are in degrees; Mahadaha and some H87 Harappa replicas analyzed with a rotation angle approximately 10% greater than for other specimens.
(v) indicates that the angular measurement is variable.
* Original calculated angle adjusted during SEM analysis.
** This field does not follow the standard numbering system (see text).

of the facet plane. Facet 5 was reserved for the rare situation (1) where three distinct wear planes were found adjacent to each other in the position of facet 1 (Kay 1977; Maier and Schneck 1981, 1982). Neither facet 4 or 5 have direct homologues in the Maier and Schneck (1981, 1982) or Kay (1977) facet numbering system, but they can probably be considered homologous to facet 1 of these two systems. Facets 4 and 5 were mapped as a backup for facets 1 and 2 if they proved to be problematic under SEM examination.

During the last phase of the study, an additional Phase I facet was mapped on cusp 3 (hypoconid) of the specimens from Harappa (H88) and Mehrgarh (MR2 and MR3). The facet, labelled facet 6, is located on the occlusal-buccal margin of the mesial portion of cusp 3, in an analogous position to facet 1. This additional facet was mapped in order to provide an alternative site for SEM analysis, if the Phase I facets on cusp 1 did not exhibit an adequate density of microwear features. Facet 6 is homologous to facet 3 of Maier and Schneck (1981, 1982) and also to facet 3 in the macaque (Kay 1977). Although micrographs were produced for facet 6 on some of the molars in the samples, in most cases metric microwear data were not collected because micrographs from the primary facets (facets 1 and 2) were of high quality.

As described in Chapter II, Phase II facets are produced during the Phase II stroke of the masticatory cycle. Crushing and grinding of the food bolus is the predominant action occurring during this part of the chewing cycle, in which the mandible is moving downward and mesially from the maxilla after having reached centric occlusion. However, some uncertainty still exists as to how much force is generated during Phase II mastication (Hylander et al. 1987; Teaford, personal communication 1991). Subsequent to this action, one or more Phase II facets are produced on the lingual surface of cusp 1. These facets are inclined at variable angles to the occlusal plane, and their surfaces may be convex, concave or planar in shape. Also, the facet surface is generally oriented in a lingual direction. Only a single Phase II facet (facet 3) was mapped during this phase of the study. The location of

facet 3 on cusp 1 is variable, but usually centrally located on the cusp surface, and often mid-way between Facets 1 and 2, but lingual to them. Facet 3 is homologous to Kay's (1977) facet x and to facet 11 of Maier and Schneck (1981, 1982). In severely worn molars, facet 3 is usually located on the buccal side of the dentinal pit worn into the center of the cusp, but still in a position lingual to the Phase I facets, and is analogous to Gordon's (1980) cusp tip facets.

SEM Analyses

Preparation for Analysis

In preparation for SEM analysis, a 200-250 Å thick layer of evaporated carbon was first applied, under vacuum, to the mounted epoxy replica. This coating of carbon provides the primary electron conductivity for the replica (Shaffer, personal communication 1988). The carbon-coated replica was then vacuum sputtered with a 150-200 Å thick layer of gold, to facilitate the production of secondary electrons when the replica is bombarded by the electron beam.

Finally, the glass slide with replica was fastened to a brass stub with silver conductive paint. As stated earlier, replicas used in later phases of the analysis were mounted directly to aluminum stubs. A stripe of conductive paint was also applied to the side of the replica and down onto the side of the stub, to eliminate charging with an excess of electrons while in the instrument chamber. The mounted specimen was allowed to dry for approximately 15 minutes in a low-temperature drying oven, before it was placed in the SEM vacuum chamber.

Analysis

Theoretical and Practical Application

A scanning electron microscope (JEOL Model JSM-35) was used for all microwear analyses conducted during this study. It was equipped with a 4-inch x 5-inch Polaroid camera and film holder, in which Polaroid Type 55 positive/negative film was used.

An acceleration voltage of 25-30 kilovolts (kV) was used for the SEM analyses, and the beam current was commonly adjusted within a range of 5 to 15 picoAmps. The use of a higher beam current would have yielded brighter and more contrasty micrographs (Shaffer, personal communication), because the effective diameter ('spot size') of the electron beam on the surface of the sample would be smaller (Goldstein et al. 1981). However, such a small impact area for a high voltage electron beam also risks burning a hole into or softening the surface of the epoxy replica. Furthermore, to produce a large depth of field at high magnifications, which is desirable with facet surfaces that vary in curvature and with features that vary in topography, a moderate beam current must be used in conjunction with a large working distance. Such an arrangement is a compromise that sacrifices surface resolution, which is better with a short working distance, for better depth of field as well as a higher signal-to-noise ratio. The latter is also desirable because a good secondary electron signal yields a low-noise micrograph (Shaffer, personal communication).

The theoretical aspects for the production of a video image on a cathode ray tube (CRT), as a result of the bombardment of a sample by high energy electrons, are fairly complicated. In general, secondary electrons are produced by a relatively small number of inelastic collisions within the first few nanometers depth of the sample. As a result of these collisions, covalently bonded and conduction band electrons are excited from their normal sites and escape the surface of the sample. Secondary electron production is relatively

independent of the atomic number of an element. Thus to a first approximation, any material stands the chance of producing as many secondary electrons as another. However, secondary electron production is very dependent upon the topography of the sample, and consequently is the principle means of imaging the surface of a sample with the SEM. In effect, the yield of secondary electrons varies with surface topography because more are produced with a high incident angle between the electron beam and the surface of the target. Consequently, the sides of ridges or troughs on the sample surface produce proportionately more secondary electrons. These topographical features appear brighter on the CRT than those normal to the incident beam of electrons, which essentially appear dark. Detailed discussions of SEM theory and operation may be found in Goldstein et al. (1981) and Wells (1974), as well as in a thesis on dental microwear (Ryan 1980).

A standardized protocol was applied to the specimens, involving SEM analysis of only homologous facets or homologous areas on platforms of occlusal enamel from worn molars. In addition, micrographs were produced of SEM fields with the instrument stage oriented so the plane of the wear facet was normal, as well as at a moderate angle of incidence, to the electron beam. My standardized protocol involved the collection of metric data from the normal fields only, whereas the tilted fields were used primarily as an aid in the recognition of features and for producing grand total feature counts from each specimen field (see below).

Each specimen was initially examined with the SEM at low power (22-50x) to ensure that the specimen was oriented correctly in the sample chamber, and to locate the appropriate facet on the protoconid (cusp 1). The specimen was then rotated to the previously calculated rotation angle and the calculated degree of tilt was applied to the SEM stage, so that the facet being analyzed was normal to the axis of the electron beam.

In such an alignment, the electron beam forms a normal angle of incidence to the plane of the facet surface. When the facet surface is in this position, it usually appears as a

darkened region against the remainder of the field (magnified area), which is usually brighter due to the topographically variable areas on the occlusal surface. Once the facet was oriented properly, magnification was increased to 500x and large areas of the facet surface were examined to obtain an overview of the general pattern of microwear features. The selection of a field to be photographed was not a random process, but based on the following criteria: (1) the field had to possess a representative sample of the types of features present on the facet surface, as well as a relatively high density of features; (2) at least some of the features, especially scratches, had to exist within the boundaries of the field (i.e., non-truncated); and (3) the existence of a nearby field that could meet the previous two criteria had to be verified. The emphasis in my study was on counting and measuring microwear features (i.e., pits and scratches), not featureless areas on enamel surfaces. Also, the exclusive presence of featureless areas or unusually low feature densities, an unfortunate but common occurrence for some poorly preserved fossil or prehistoric samples, is usually a sign that the specimen is suspect and should be removed from the sample (Teaford 1988b). Although feature counts for some prehistoric groups are in the range of 50 or more, and considerably higher for many extant primate populations (Teaford, personal communication 1990), it is possible that lower feature counts are characteristic of other prehistoric populations.

Multiple micrographs were taken at 500x of the two Phase I facets. These included micrographs taken of the aforementioned adjacent areas (fields) on each facet, and tilted and 'normally' oriented micrographs produced of each field. During the initial phase of this study, Polaroid Type 52 black-and-white positive film was used to produce the micrographs. However, this photographic film does not produce a negative that can be used for archival purposes or to produce additional prints. Consequently, Polaroid Type 55 positive/negative black-and-white film was used during most of my study.

The secondary electron detector (collector) of the JEOL instrument is positioned at a

45 degree angle from the horizontal plane of movement (X-axis) of the instrument stage. Gordon (1988a) noted that the visibility of microwear features may be affected by collector geometry. In fact, a bias exists in favor of elongated features (i.e., scratches) that are oriented at right angles to the specimen-collector axis. Features oriented on the facet surface at angles more parallel to this axis will be less visible. If the specimen orientation with the detector is not controlled in some fashion, it will introduce unknown sources of variability into the analyses. Micrographs produced from specimens with a standard orientation also bias feature counts and frequencies, but with greater control over the variability. Feature dimensions may also be differentially affected by variation in the SEM stage rotation, and the subsequent variation in specimen-detector geometry (Gordon 1988a).

In a quantitative analysis in which the dimensions of microwear features are measured, it may be important to assess only fields which are at right angles (normal) to the axis of the electron beam of the microscope (Boyde 1970, 1974, 1979). Such an orientation eliminates foreshortening of features that are parallel to the axis of the secondary electron detector (Gordon 1984a, 1984d, 1988a). This arrangement will diminish the foreshortening of elongated features which are perpendicular to the axis of tilt of the specimen stage. Conversely, those features that possess an orientation more closely parallel to the axis of stage tilt will retain their true dimensions, despite the degree of tilt provided to the stage.[1] Foreshortened field widths are also attributable to the use of strongly tilted orientations for the instrument stage. In other words, at high incident angles the area actually scanned on the facet (field) becomes larger, occasionally revealing additional features or parts of features not visible on the normal field. This is due at least in part to the physical phenomena of an increase in the area of projection of a plane onto another surface, as the latter is inclined away from a parallel position to the projecting

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1 A linear feature oriented in the direction of tilt will distort (shorten) as a function of the cosine.

plane.

Statistical comparisons were performed, using paired Student's t-tests, on lengths and widths of features measured on normal/tilted micrograph pairs from five of the Mahadaha specimens. Results of these comparisons revealed significant differences in length measurements of features for two of the paired samples, and for width measurements with one of the paired samples. Lengths of scratches can vary between 4 and 5 percent when a matched normal field is compared with its tilted field. As described above, this variance encompasses slightly greater lengths of scratches from normal fields, when they are oriented parallel to the axis of stage tilt, and shorter lengths for normal-field scratches oriented more perpendicular to this axis. However, "significant" differences between normal and tilted micrographic fields may not interfere with statistical comparisons of measurements between the archaeological groups (see Chapter VII).

Because of the inherent imaging features of the SEM, a specimen at an oblique angle to the axis of the electron beam produces a much better quality micrograph (Goldstein et al. 1981). As a result, the visibility and ease of measuring microwear features on such a micrograph are also much better. However, in this study micrographs were only produced with each specimen in a predetermined position on the instrument stage. This standard alignment ensured that each time a micrograph was taken, the facet surface of each specimen was similarly aligned with respect to the axes of the electron beam and to the secondary electron detector.

In summary, such a standard protocol, applied rigorously throughout this study, is capable of limiting the inter-individual variation in dental microwear, which could be attributed to specimen-beam and specimen-detector geometry. As a result, any quantitative microwear variation between individual specimen fields can be attributed to functional or dietary causes, rather than to differences in instrumentation methods.

Examination of Facet Surface

With exceptions, I adopted the research protocol presented by Teaford and Walker (1984). One of the unique aspects of their protocol is the use of a relatively high magnification (500x) for the SEM analysis of facet surfaces. Other investigators have used relatively low magnification (100-200x) for SEM analyses of dental microwear (e.g., Gordon 1980, 1982, 1984b; Grine 1981, 1984, 1986).

In preparation for the production of micrographs, the SEM stage was moved along the X and Y axes (cf. Gordon 1988a, Figure 1) to examine a series of fields across the facet surface. A representative microwear pattern was defined as one in which the density and types of microwear features were relatively typical for a particular facet. In practice, this was not a random or quantitative process, but involved a qualitative judgement, based on the appearance of the enamel fabric displayed on the CRT. Another aspect of the protocol was to find two adjacent but separate fields of view, if possible, which exhibited similar but not necessarily identical microwear patterns. For example, if only a limited area of the facet exhibited a few scratches, then this area was not selected for analysis. This conservative approach avoided selecting an aberrant area of the facet, which may have been affected by diagenetic processes or had been damaged by museum preparation activities. In questionable cases, areas of the tooth crown not normally subjected to occlusal action during the masticatory cycle, such as interproximal facets, were examined to characterize the microscopic pattern on these enamel surfaces. This procedure ensured that only actual microwear features on a wear facet were selected for analysis (Teaford 1988b; Teaford, personal communication 1991).

In most cases, the two adjacent fields were mapped on the facet surface by recording the number of full and partial field widths between them, and the direction of travel of the SEM stage as it passes from one to the other. Distances between the selected fields varied, with adjacent ones sharing field borders, while in other cases the two selected

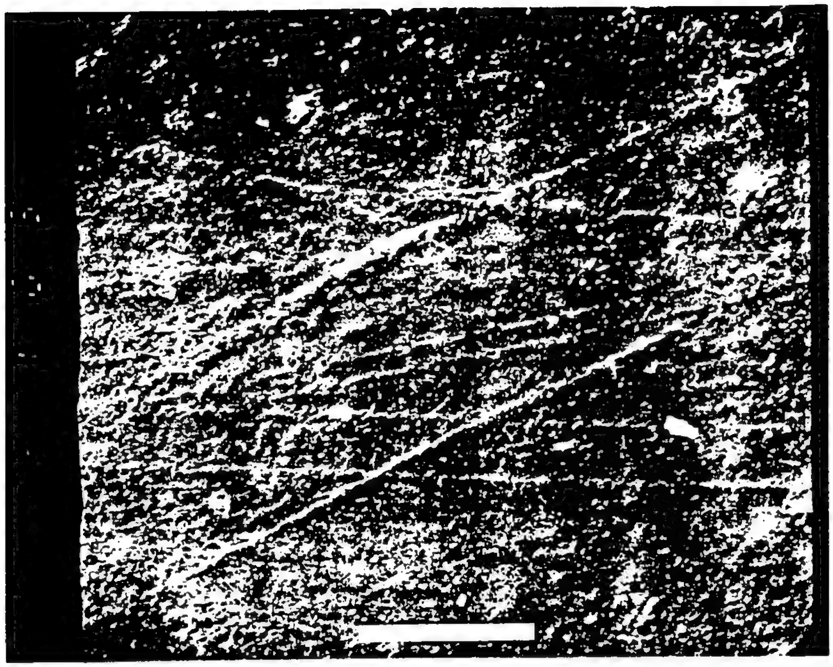
fields were several field widths apart. At 500x, distant fields on some facets are several hundred micrometers apart. The actual dimensions of a 500x field, as measured on a micrograph produced from the JEOL instrument, are 204 μm in length and 180 μm in width.

Micrograph Production

With few exceptions, normally tilted micrographs were produced of two adjacent microscopic fields for each of the Phase I facets of every specimen. An additional 'tilted' micrograph was produced for each of the normal fields, in which case the plane of the SEM stage was tilted 10-15 degrees from the 'normal' position and generally in a direction toward the secondary electron detector. Micrographs produced with the instrument stage in a tilted position are uniformly brighter and possess higher photographic contrast than the normal micrographs. Generally, the microscopic features are much more apparent in the tilted fields, and the overall number of observable features is usually greater. However, as previously stated, the use of normal micrographic fields controlled for variability in feature dimensions, but possibly at the expense of not completely characterizing the microwear pattern on the teeth, as revealed in the tilted images (i.e., some features are not present in the normal images). In most cases, micrographs were also produced for facet 2, although these micrographs were only digitized in rare instances when a facet 1 micrograph was not useable. Consequently, a total of eight normal and tilted micrographs was produced for most tooth specimens analyzed.

During the final phase of the SEM analyses, the Harappa specimens replicated during the 1988 field season (H88 specimens), and many of the re-cast Mehrgarh teeth, were analyzed with the SEM stage tilted 25 degrees from the 'normal' position. A qualitative comparison of the high tilt micrographs with those produced at 15 degrees of stage tilt (Figure 4.3) showed that foreshortening did not occur to a greater extent in the

a



b

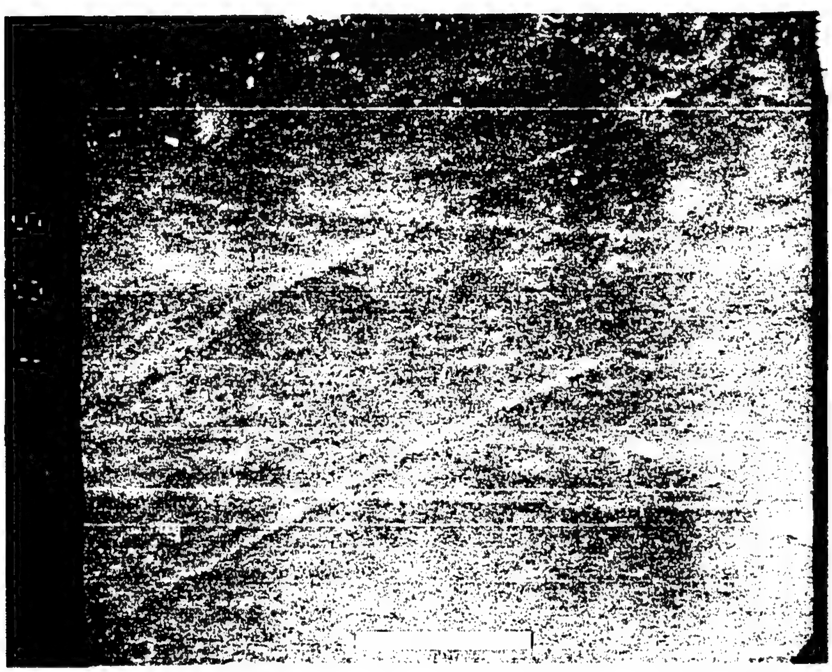


Figure 4.3. Comparison 500x Micrographs of (a) 15 Degree Tilted Field (AA1-4513), and (b) 25 Degree Tilted Field (AA1-4515) from Shearing Facet on First Molar Specimen AA1-H87-145.

higher tilt field, and that feature dimensions were approximately identical in both tilted fields. The more strongly tilted field produced a more contrasty micrograph, however, in which most microwear features were more highlighted and more readily apparent than the mildly tilted field. These tilted fields were used, as were the others, as a visual aid for the recognition of indistinct or dim features on the normal fields, and for producing a tally of features not measured on the normal field. This tally, the Unmeasured Count, is discussed in greater detail in a later section.

Since this was initially a blind study, a specimen numbering system was devised for use during the SEM analyses, and for associating micrographs with the specimens from which they were taken. All micrographs were assigned a four digit code (Lab Number) for identification purposes. The first two digits in the sequence correspond to the alphabetic character label of each specimen, numbered sequentially according to their alphabetical order (see Table 3.1). For example, specimen H1 is a first molar from individual 'H', which is assigned number 15 for the first two digits of the four digit numbering scheme, as determined by its ranking in alphabetical order (i.e., A = 1, B = 2, etc.). The third digit represents the facet number, and can vary from 1-4. As previously described, facets 1 and 2 are Phase I facets located on the protoconid (cusp 1) of the lower molars. The former facet is adjacent to the buccal pit and/or buccal groove. Accordingly, a '1' in the third digit of this numbering scheme indicates that the micrograph was taken of facet 1, and a '2' represents a micrograph of facet 2. Accordingly, other wear facets are represented by their corresponding identification number in this part of the lab code. The fourth number (1-4) in the four digit specimen numbering scheme represents the field of SEM analysis, for the particular facet analyzed. A '1' or '2' represents an adjacent field, each of which is normal to the electron beam. Higher contrast micrographs were produced at 10-15 degrees of stage tilt, and these correspond in location to each of the normal fields. A '3' represents the tilted view of normal field 1, and a '4' represents the tilted view of field 2. With regard

to the H88 and some Mehrgarh specimens, the strongly tilted fields were labelled with a '5' or '6' to indicate that they are high contrast views of fields 1 and 2, respectively.

In most cases, only micrographs taken from the normal fields were digitized, although there were exceptions to this protocol. For example, an occasional normal micrograph exhibited so little detail that it was necessary to use the tilted field as the principle digitized field for the facet. Also, when some of the specimens analyzed with the SEM during early phases of this study, in which tilted micrographs were not originally collected, were reexamined it was found that some of these original fields had actually been analyzed with a slightly tilted stage geometry. When time permitted, an additional micrograph was produced from the newly examined normal field, and this normal micrograph was digitized as part of the principle sample of normal micrographs. In any case, the frequency of tilted fields used for metric analysis was very small.

Specimen laboratory numbers and field numbers, corresponding to the degree of inclination of the instrument stage, are listed in tables in Chapter VI. Tilted fields were used primarily as a guide to help ascertain the extent of features, since these micrographs usually revealed much more detail than those produced with a stage possessing a normal inclination to the electron beam. Acetate transparencies (described below) created during the data collection phase of the study represent only features identified and measured on these normal micrographs.

Digitizing Sessions

A Kurta IS/ONE™ digitizing tablet, measuring 12 inches by 12 inches, with Penworks™ driver software was used to collect linear measurements of dental microwear features from specimen micrographs. The actual measurement of features was accomplished with a moveable puck connected by cable to the tablet.

A Macintosh Plus™ computer interfaced with a Mirror Technologies™ 40

megabyte hard drive was used to collect and store the metric data from the digitizing tablet. Custom software, written by Mr. Anthony Michaels, provided an interface between the Penworks™ program and the Macintosh™ computer. The program, written in the C language, facilitates the collection of length and width measurements of microwear features, keeps a running count of features measured, calculates a proportion for the ratio of width/length (Ratio), produces a categorical description of each feature based on the ratio, and records the total number of features not analyzed on a micrograph (Unmeasured Count). The linear measurements, proportions, and categorical descriptions for each micrograph were recorded in a separate computer file and saved onto a floppy disk (Tablet Data). Editing of the data files was not possible in the original digitizing program, but was facilitated through the use of several commercially available statistical and spreadsheet programs.

Recognition of Microwear Features

The categorical sorting of features by width-to-length ratio relied upon the following protocol, which is based on a 1:4 cut-off point: (1) any feature with a width/length ratio greater than or equal to 0.26 is categorized as a pit; and (2) a feature with a ratio between 0.25 and 0.01 is categorized as a scratch. This protocol follows the evidence from earlier dental microwear studies which showed that a 4:1 ratio of length:width for categorizing pits and scratches corresponded best with the perceptions of impartial observers, who were asked to qualitatively categorize microwear features (Grine 1986; Walker and Teaford 1989). The arbitrary 10:1 cut-off point used earlier by Teaford and Walker (1984) to categorize microwear features was found to incorrectly assign many short features as pits, although they qualitatively would be analyzed as gouges or scratches (Walker and Teaford 1989). In the present study, gouge-like features are subsumed under the scratch category as a result of the 1:4 cut-off point for the width-to-length ratio.

Additional discussion of the ratios used for categorically sorting features is addressed in a subsequent section on microwear variables.

The conservative approach to pit recognition and measurement recommended by Teaford (1988:34) was adopted in this study. This involved counting as a single composite pit any medium to large feature with an irregular-shape, which surrounds and unites two or more smaller irregular depressions that are all united by at least one common (i.e., shared) border or boundary.

As other researchers have noted, micrograph fields produced at a magnification of 500x or higher exhibit many microwear features (pits or scratches) truncated by the margins of the field (Gordon 1980, 1982; Teaford 1988a; Teaford and Walker 1984). My research followed Teaford's and Walker's (1984) protocol for counting and measuring all truncated pits and scratches. Teaford (personal communication) considers the maximum diameter of a truncated pit to represent the length, and the minimum diameter measured at right angles to the length measurement to represent its width. Although one can never be certain of the actual shape or true size of truncated pits, it was felt that the additional information contributed by truncated pit data (e.g., higher feature counts) would outweigh any potential measuring errors. I used length measurements only to produce a width-to-length ratio for categorizing scratches and pits. Therefore, any error in the length measurement of a truncated scratch or pit would be inconsequential to the analysis.

Acetate Transparencies

A transparent acetate overlay was cut to the approximate dimensions of the micrograph, and taped over it prior to beginning the digitizing session for each micrograph. Each acetate transparency was used to record the locations and types of microwear features measured on the normal micrograph. A similar technique was used by Kay and Grine (1988) in their research on australopithecine molar microwear. In this way, the

transparency provided a graphical representation of the microwear pattern on the tooth surface (Figure 4.4). Scratch length was represented by a long thin line drawn with a fine-tipped permanent marker on the transparency, in the approximate position of the scratch on the micrograph. In the relatively rare case of a very wide scratch, the line was drawn along the approximate centerline of the scratch. Also, the few slightly curved scratches appearing on micrographs were represented by lines drawn on the transparency to follow the scratch curvature. The width measurement was represented by a line drawn on the transparency in the approximate position in which the measurement was taken and approximately normal to the line representing the length.

Microwear features recorded as pits were represented on the acetate transparency by a line drawn to represent the approximate outline of the feature, most often in the shape of a circle or oval. During early phases of this research, large pits (judged subjectively) were represented by a simple outline drawn with a marker pen around the perimeter of the feature. Medium pits were represented by an outline filled with hatched lines, and small pits were represented simply by an outline or by a solid circle or other shape. During later phases of the present study, features of any size that were categorized as pits were represented on the acetate transparency by a simple outline which corresponded to the perimeter of the feature.

Qualitative Analysis

In addition to the quantitative analyses, a qualitative approach was used to categorize and analyze microwear features. Essentially, a microwear feature that is long and linear, possessing a length that is noticeably greater than its width, is categorized as a scratch (striation). Consequently, a circular feature or a linear one possessing a length more equivalent to its width is categorized as a pit. In addition, a feature with a length approximately twice that of the width was categorized as a gouge, a type of feature also

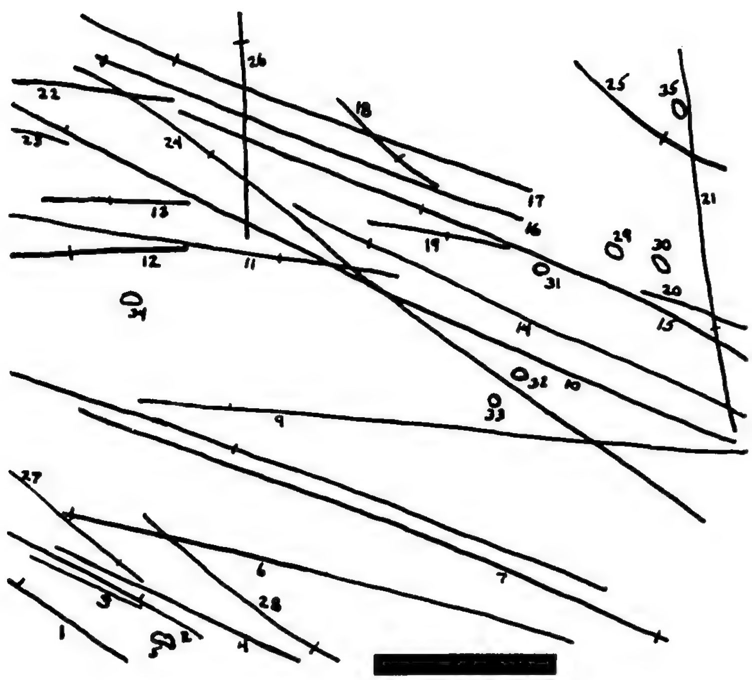


Figure 4.4. Acetate Transparency of 500x Field 1511 from Second Molar Specimen H2-MR2-34.

recognized by Gordon (1980, 1982). Microwear features categorized as pits or scratches by impartial observers inevitably corresponded to a 1:4 ratio of width:length, and followed a 0.25 ratio cut-off point for scratches (Grine 1986; Kay and Grine 1988). Such qualitative categorization follows closely that used quantitatively, as discussed in detail in a subsequent section.

The orientation of scratches on the facet surface has been shown to be a useful interspecies discriminator when used with fossil hominids and extant species of primates (Gordon 1980, 1982; Grine 1981, 1986; Kay and Grine 1988; Puech et al. 1983; Puech et al. 1989). However, scratch orientation has not proven to be a reliable intra-species discriminant variable (Gordon 1980; 1982), although analyses to-date have been on small samples. Consequently, I decided early in my study not to collect detailed quantitative data on feature orientation. However, the qualitative phase of the microwear analysis encompassed the analysis of scratch orientation according to the following protocol.

The mounting and orientation of specimens in relation to the SEM stage was partially standardized, as described previously, so that the orientation of the SEM field across the facet surface could be interpreted by examining low and high power fields of view shown on the CRT. In this study, scratch orientation has not been measured in terms of degrees of rotation from a standard axis of a tooth, although such a technique has been used in previous microwear studies (e.g., Teaford and Byrd 1989). Instead, scratch orientation has been categorized in general terms relative to point and line angles of a tooth (Fuller and Denehy 1984:18). Essentially, this scheme provides increments of 45 degrees for describing scratch orientation, with an accuracy of ±22.5 degrees. For example, a scratch oriented diagonally across a high-power specimen field, might be recorded to have a mesiobuccal-distolingual direction, while horizontal scratches on such a field would possess a buccolingual orientation. Such data are reported as part of the qualitative analysis of microwear in Chapter V.

Microwear patterns were also analyzed using several qualitative categories described by Rose and colleagues (e.g., Blaeuer and Rose 1982; Harmon and Rose 1988) for four prehistoric cultural traditions from the southeastern United States. These qualitative categories, described for SEM micrographs taken at very high magnification (1500x), include: 1) polish, which is defined as any area of flat, featureless enamel; and 2) striation margin morphology, considered in terms of relative sharpness, roughness, roundness and smoothness of the scratch margins and troughs. Scratches can range along a continuum of these qualities. However, direct comparisons of qualitative microwear patterns, or feature dimensions and frequencies observed in the present sample with those from the southeastern United States is not possible, because of the different magnifications used in each study. For example, a polished surface at relatively high power may not appear the same at lower magnification. In other words, the smooth surface may appear rougher when examined with SEM at medium power. At present, the lack of standardization of materials and research protocols among dental microwear investigators is a hindrance to a comparative approach using results of the present and other studies (Gordon, personal communication 1990). The results of my qualitative analyses are discussed in detail in Chapter V.

Additionally, the macroscopic attrition of each tooth specimen was analyzed qualitatively for such characteristics as dentine exposure, relative amount of enamel present, overall severity of occlusal wear and the inclination of the occlusal wear plane. Special care was taken when tooth replicas were examined and analyzed for wear, to avoid mistaking noncarious pits or casting artifacts for dentine exposure (Scott 1979a). Also described was the occlusal morphology of the molars, including cusp morphology, sulcus (groove) pattern, and the existence of non-metric traits, such as the buccal pit.

Measurement of Feature Dimensions

All features were analyzed for maximum length and width. This was a fairly straightforward procedure in the case of pits, in that the length was measured along the longest axis of gouge-like features and at the maximum diameter of more circular features. The width of composite pits was measured in a similar fashion. Scratches often possessed pits at one end (Ryan 1979, 1979b; Teaford and Walker 1983) or frequently along central portions of the length. In such cases, several width measurements were taken, but only the maximum width measurement was collected and stored in the computer file for each particular feature. Width measurements of pits or scratches were always taken perpendicular to the axis along which the length measurement was taken. The length of a truncated scratch was determined by measuring the maximum length between field borders. The length measurement collected for the relatively rare curved scratch encountered on a micrograph does not represent its true length, because the digitizing program was only capable of recording point-to-point distances. Thus, slightly curved scratches are recorded as if they were strictly linear features. Consequently, the lengths of such curved scratches were recorded slightly shorter than the true length, although this matters little for calculation of the width:length ratio or for sorting features into categories.

The measurement accuracy of the Kurta digitizing tablet was 40 points per millimeter. In other words, the highest accuracy obtainable for linear measurements was 0.025 millimeters (0.0025 centimeters), the minimum distance established between 2 points on the face of the Kurta tablet. When scaled to 500x (measurement in centimeters x 20), the greatest measurement accuracy would theoretically be 0.05 micrometers. However, the accuracy of dimensions measured on a micrograph depends on its quality and resolution. The greatest resolution obtainable from Polaroid Type 55 film is 10-15 lines per millimeter (Shaffer, personal communication 1993), which is equivalent to approximately 0.1 micrometers on a 500x micrograph. Therefore, width and length measurements were

recorded to a tenth of a micrometer, reflecting the maximum precision obtainable from the micrographs at 500x (see Chapter VI).

Features not originally measured on the normally tilted field, because of their faintness, were included in the unmeasured count category. The unmeasured count includes features not visible on the normal field, but apparent on the companion tilted field. During the initial phase of this project, some pits that were truncated by the margins of a specimen field were not analyzed. However, later phases of my research incorporated these truncated pits, to increase the feature count for each specimen field, and to allow comparison of the results with those of Teaford and other investigators. Consequently, a small number of the specimen fields (Mahadaha) analyzed initially included such truncated pits in their unmeasured count category. Due to the time-consuming nature of the measuring/digitizing process, these features included in the unmeasured count were only categorized qualitatively as either pits or scratches (Grine 1986), based on an approximately 1:4 ratio of width-to-length, and a schematic representation of each feature was drawn on a separate acetate transparency for each specimen field. Using this procedure for the companion tilted fields, the unmeasured count was compiled as an additional variable for each normally-tilted specimen field and used to produce a grand total feature count, as well as grand totals of pits and scratches, for each specimen field. These matters are discussed in greater detail in Chapters VI and VII.

Statistical Analyses

Variables

Individual microwear features on an occlusal wear facet cannot be assumed to be random (Teaford 1988a, b; Teaford and Walker 1984). In other words, individual features, especially scratches, may not be produced by independent occlusal events.

Consequently, only means of variables will be compared per individual specimen field (i.e., specimen means), in lieu of comparing the dimensions or frequencies of individual microwear features on an intra-specimen basis.

As discussed previously, the two primary metric variables collected in this study are the maximum width and length of microwear features. These data were originally collected in centimeters, but converted to micrometers (µm) for use in the statistical analyses, as well as for all raw and computed values reported in this study.

Many of the variables (parameters) selected for use in the statistical analyses follow those used by Teaford and colleagues (Solounias et al. 1988; Teaford 1988a, 1988b, 1989). Because the feature length is truncated in the case of many long scratches, length is not very useful as a separate variable in the analyses. Instead, I use feature length primarily to produce a ratio of width:length, by which pits and scratches are differentiated. Other variables computed from the raw data for width and length are as follows: ratio of width-to-length; feature counts; and feature frequency.

As discussed previously, a ratio of length:width has been used by other investigators (Grine 1986, 1987; Kay and Grine 1988; Teaford 1985; 1988a, 1990) to categorically order features by shape. However, I elected to calculate this ratio in terms of width:length, because the resulting values are proportions which are consistent with the other frequency data reported in the study. For example, a scratch is a categorical variable, based on a width:length ratio of 1:4 or less, a proportionally identical sectioning point to that used in other studies. A 1:10 ratio of width:length was tested on a small subset of the archaeological samples for its ability to distinguish between the samples, but the data are not reported here. All ratio data were transformed to their arcsin, to normalize them, although this procedure is only necessary with values at the tails of a distribution of proportions (Sokal and Rohlf 1969; Zar 1984).

Feature counts were calculated for the following: (1) total number of scratches per

field; (2) total number of pits per field; (3) total number of features per field (pooled features); and (4) unmeasured count. In this study, feature density was not calculated as a factor of the area of the micrograph, but such data has been reported by other investigators (e.g., Grine 1986; Kay and Grine 1988). Feature frequency is reported for the relative proportion of scratches, as well as for pits. Although my width:length ratios are not directly comparable with other studies, feature type and frequency data are comparable.

Scratches or pits of a specified length or width are often useful discriminant variables in a quantitative microwear comparison of different species or archaeological groups (Solounias et al. 1988; Van Valkenburgh et al. 1990). For example, microwear features less than 30μm in length have been shown to discriminate between fossil and extant carnivore taxa (Van Valkenburgh et al. 1990). Solounias and colleagues (1988) successfully used both small and large pits and also narrow and wide scratches to separate extinct species of ruminants, based on diets inferred from dental microwear. In this study, pits are sorted by width using a 5 μm sectioning point, while scratches 2μm or less in width are sorted from the wider scratches.

Occlusal surface attrition of each molar specimen was determined with both the naked eye and a 10x hand lens, and Molnar (1971) and Scott (1979) wear scores were recorded for each tooth (see below). All individuals considered in this paper had the normal complement of molars on both sides of the jaw, with the exception of Mahadaha individual MDH-1 in which only the left side of the mandible was preserved. The small sample sizes and balance of distribution toward males in the Mahadaha sample, and toward females in the Harappa sample, precluded any meaningful comparison of gender differences in grades or gradients of attrition (Lunt 1978). Because of the equal sex distribution, the chalcolithic Mehrgarh sample lends itself more easily to testing gender differences for attrition, although small sample size remains a problem (Pastor 1991).

Two methods were used to score attrition on the molars: Molnar's (1971) 1-8

system for scoring the degree and form of attrition, which provides additional information on the angle and shape of the wear plane; and the more comprehensive 1-40 system for scoring rate of wear, proposed by Scott (1979). The latter scoring system records a cumulative score for four quadrants of a tooth, and it is capable of yielding lower variances and smaller confidence limits in a quantitative analysis of occlusal wear. The degree of attrition exhibited by specimens is discussed in conjunction with the qualitative comparison of microwear between samples (Chapter V), as well as quantitatively with respect to the relationship between macroscopic and microscopic dental wear (Chapter VI).

The relative closeness in age of death (young adult to adult) for 4 out of 5 of the Mahadaha individuals, for 3 out of 5 of the chalcolithic Mehrgarh individuals, and for 7 out of 8 of individuals from Harappa means that age was essentially controlled for in the comparison. Therefore, attritional differences within and between the samples must be due primarily to individual variation in mastication, diet, food preparation, or the use of the posterior teeth in non-masticatory behavior (Molnar 1972).

Socio-cultural and ecological data are used as explanatory factors, to more fully explore the relationship between dental microwear patterns or specific parameters of microwear and functional or dietary causes for the production of microwear features. These data incorporate the archaeological evidence for status, diet, food procurement, and food preparation.

A progressive increase in socio-cultural complexity has often been observed in the archaeological record of both the New and Old Worlds (Eddy 1991). As discussed in Chapters I and III, this is true for the archaeological samples used in this study. In addition, the socio-cultural status of individuals in the populations, especially at Harappa, may also be associated with different diets. Archaeological evidence (quality of burial goods) and paleopathological evidence (incidence of hypoplasia) suggest that socio-cultural status, as well as nutritional status, at Harappa were associated with the sex of an inhabitant

(see Chapter III). This difference in socio-cultural status may also be reflected in the diets, as evidenced by inter-individual differences in dental microwear. Although small sample size may be a problem in this study, inter-sample variability is explored for the Harappa sample to determine if gender differences exist in the microwear data, such as the relative proportion of pits on first and second molars.

Other archaeological evidence, such as stone mortars, pounders, and ceramic vessels, are utilized as indirect evidence for diet, food procurement, and food preparation activities. In some cases, I attempt to associate the dental microwear exhibited by a particular archaeological sample with the tools for food preparation. For example, feature frequencies observed for the chalcolithic Mehrgarh and Harappa samples may be significantly influenced by the use of stone grinding implements for processing the wide array of cultivated grains at the two sites (see Chapter VII).

Trace element analyses have not proven useful in these archaeological populations, because of problems of diagenesis (Radosevich 1989a, b). However, more recent evidence indicates that at Harappa the sex differences for diet, based on trace element analyses, may be strong enough to outweigh the effects of diagenesis (Radosevich 1990).

As detailed in Chapter III, faunal and botanical evidence has been recorded for all the archaeological sites used in this study, although the quality and quantity of evidence is variable between the sites. In some cases, these may be limited to only presence/absence data. In general, a considerable amount of information is available on the contribution of meat or plant foods to the diets of these archaeological groups. In addition, the data from some of the sites is sufficient to allow the proportion of wild foodstuffs to be compared to that of domestic foodstuffs. However, evidence for some variables remains equivocal. For example, in many cases no certain evidence exists to show that domestic ungulates were not used for draft animals rather than as a dietary component.

No attempt was made to transform the faunal and botanical data from the sites into

proportional values for use as variables in the quantitative comparisons. Where the data are sufficient, conclusions can be drawn about the contribution of specific groups of foodstuffs to the production of microwear features. For the most part, the archaeological groups will be referred to in general terms, such as incipient agriculturalist or hunter-gatherer, when the archaeological samples are compared for microwear differences.

Univariate and Multivariate Statistics

Descriptive statistics were used for the initial exploratory investigation of the data. The total sample size for all molar specimens used in the quantitative microwear analyses was 31. Because only homologous teeth were compared in the statistical analyses, the sample size of first molars was 16 (MDH, n = 5; MR3, n = 2; MR2, n = 5; H88, n = 4). The sample of second molars consisted of 15 specimens (MDH, n = 5; MR3, n = 1; MR2, n = 5; H88, n = 4). The only unerupted and unworn molar tooth in the sample (specimen MR2-36A-F; see Table 3.1) was eliminated from the statistical analyses of the archaeological samples. This is because the naturally low feature densities on unworn teeth would skew the comparisons. In addition, the descriptive statistics (e.g., variances and coefficients of variation) and normal probability plots were examined to check that feature frequencies and feature dimension variables were continuous and normally distributed (Sokal and Rohlf 1969; Velleman 1988; Zar 1984). The computed specimen means for the microwear variables were used in all subsequent analyses. Prior to performing the statistical analyses, many of the raw data were normalized using several transformation procedures: the arcsin for ratio data; log transforms of linear measurements; and square root transformation of raw counts (Zar 1984). Only homologous molars were used in the comparisons, to avoid skewing the observed relationships.

Univariate statistical analyses used in this study consist primarily of the Student's t-test and single-factor analysis of variance (ANOVA). These analyses used feature means

(subject means) from each specimen field, as well as means for each group (group means).

The principle use of the analysis of variance was to indicate whether any significant differences existed among a sample of specimen fields, based on a particular microwear variable. As a precursor to the multiple comparison analyses, this is a necessary step that ensures that significant differences exist in the sample, but is not capable of revealing specifically where the significant difference lies (Zar 1984). Kruskal-Wallis nonparametric ANOVA was used rarely, when the descriptive statistics revealed that the samples did not come from normal populations.

Multiple comparison tests can reveal which population means differ, and how many total differences exist, based on some or all of the microwear and attrition variables. A multiple comparison computer program, based on the Tukey HSD test for unequal sample sizes (Zar 1984:316), was written by Mr. Anthony Michaels. The Tukey test uses pairwise comparisons of means, and it also normalizes the samples (Zar 1984), thus eliminating the need to apply a separate normalization procedure. The Student-Newman-Keuls test is a multiple range test, using ranked means, that can be corrected for unequal sample sizes (Zar 1984). The Newman-Keuls test and the Kruskal-Wallis test, a nonparametric multiple comparison procedure adjustable for unequal sample sizes, were tested on a small subset of the microwear data, but these tests were not used for a significant number of comparisons.

Because the size of the archaeological samples was not equal, a specified sample size could have been randomly selected from each to equalize sample sizes, and to preserve maximum power and robustness of these tests. However, the generally small sample sizes and occasionally high variability within the samples limited the power of some of the multiple comparison tests to produce significant differences despite their existence, a problem known as a type II error (Keppel 1982; Sokal and Rohlf 1969; Zar 1984). The extremely small size ($n = 2$) of the neolithic Mehrgarh (MR3) sample was an especially critical limiting factor in the power of comparison tests involving the other samples, as well

as contributing to the chance of a Type I error (Games and Howell 1976). The Bonferroni procedure is an even more conservative approach to adjusting individual confidence levels when using a multiple interval test (Weir 1990; Velleman 1988). Although it is wise to protect against Type I errors, such a procedure applies an unreasonably stringent probability level on each individual test (Weir 1990), and thus was not chosen for use in this study. For these reasons, some of the separate comparisons of sample means for a particular variable were performed using individual t-tests. Such separate tests, although cumbersome and numerous, often revealed significant differences between two samples not shown by the multiple comparison tests for the same variable (s). This is because multiple range tests do not allow the conclusion of significance between two sets of means if they are enclosed by one or more nonsignificant sets (Sokal and Rohlf 1969; Zar 1984). However, caution must be used when interpreting the results from such comparisons, because in a large series of independent two sample comparisons, a certain number of significant differences will be found by chance alone.

Multivariate analyses (principal components and discriminant functions) of group differences were applied to the data sets for significant variables. The theoretical aspects of these multivariate procedures, and the results of these and the other statistical analyses are discussed in detail in Chapter VI.

CHAPTER V

RESULTS: QUALITATIVE ANALYSIS

Introduction

This chapter presents the qualitative analyses and comparisons of the dental microwear exhibited by individual specimens from the four archaeological samples. A single 500x micrograph of a Phase I facet from each tooth specimen is presented. The specimens are listed and described by archaeological site, in diachronic order: (1) mesolithic Mahadaha; (2) neolithic Mehrgarh (MR3); chalcolithic Mehrgarh (MR2); and (4) bronze age Harappa. Dental microwear patterns were qualitatively analyzed, and four features of each specimen are described in detail below. These features include the appearance of the enamel fabric, the microwear feature density, the size and morphology of scratches and pits, and the orientation of scratches. Furthermore, any gross or microscopic, diagenetic or casting defects on the occlusal surfaces were noted.

The macroscopic wear of each molar specimen was analyzed qualitatively, as well as quantitatively. These results are reported in detail for each specimen. Molnar wear scores (direction, form, degree) and Scott wear scores (by quadrant and total) for all specimens, as well as information on the archaeological provenience, biological age and sex of the individuals, are listed in Table 5.1.

Accompanying the micrographic illustrations are xerographic copies of acetate transparencies of the microwear features from the specimen fields, which graphically illustrate the microwear pattern. In addition, a line drawing is presented of a macroscopic view of the occlusal surface of a representative molar from each of the samples.

Table 5.1. Micrographs, Archaeological Provenience, and Molnar and Scott Wear Scores for Prehistoric South Asian Sample of Permanent Mandibular Molar Teeth

SPECIMEN NO.	MOLAR TYPE	PROVENIENCE	AGE/SEX	MOLNAR SCORE			SCOTT QUADRANT SCORES				
				Direction	Form	Degree	Quad 1	Quad 2	Quad 3	Quad 4	Total
A1-0121	LM1	Mehrgarh (MR2-42)	Adult / Male	3	3	4	6	4	7	4	21
A2-0212	LM2	Mehrgarh (MR2-42)	Adult / Male	3	3	2	3	2	3	2	10
B1	LM1	Harappa (H87-37)	11 yr / ?	3	3	3	5	2	5	2	14
B2	LM2	Harappa (H87-37)	11 yr / ?	1	1	2	2	1	1	1	5
C1-0517T	RM1	Mehrgarh (MR2-60)	16 yr / Female	3	3	3	5	1	4	2	12
C2-0617N	RM2	Mehrgarh (MR2-60)	16 yr / Female	3	3	3	3	1	2	2	8
D1	LM1	Har (H87-60-46a-36)	20 yr / Female	3	2	4	6	4	5	4	19
D2	LM2	Har (H87-60-46a-36)	20 yr / Female	3	4	2	3	2	3	2	10
E1	LM1	Harappa (H87-71)	22 yr / Female	3	3	3	6	3	5	3	17
E2	LM2	Harappa (H87-71)	22 yr / Female	3	4	2	4	2	4	3	13
F-1111	RM1	Mehrgarh (MR2-36A)	4.5 yr / ?	1	1	1	1	1	1	1	4
G1	RM1	Harappa (H87-85)	30 yr / Female	3	3	4	6	5	5	3	19
G2	RM2	Harappa (H87-85)	30 yr / Female	2	4	2	3	1	3	3	10
H1-1417N	RM1	Mehrgarh (MR2-34)	Y. Adult / Male	3	4	2	3	2	3	1	9
H2-1517T	RM2	Mehrgarh (MR2-34)	Y. Adult / Male	1	1	2	2	2	2	1	7
I1-1627T	LM1	Mehrgarh (MR2-45)	Adult / Female	3	4	3	6	3	6	3	18
I2-1767T	LM2	Mehrgarh (MR2-45)	Adult / Female	3	3	3	4	1	5	2	12
J1-1827T	RM1	Mehrgarh (MR2-46)	11-12 yr / ?	3	3	3	5	3	5	2	15
J2-1917T	RM2	Mehrgarh (MR2-46)	11-12 yr / ?	1	1	2	2	1	2	1	6
K1	RM1	Har (H87-60-46a-32)	20 yr / Female	3	3	2	3	2	3	2	10
K2	RM2	Har (H87-60-46a-32)	20 yr / Female	1	1	1	1	1	1	1	4
L1	LM1	Harappa (H87-85)	30 yr / Female	3	3	4	6	3	5	3	17
L2	LM2	Harappa (H87-85)	30 yr / Female	3	4	2	3	3	3	2	11
M-2447T	RM1	Mehrgarh (MR3-35)	Y. Adult / Female	3	3	4	5	3	5	3	16
N1-2512	RM1	Mehrgarh (MR3T-S36)	15-17 yr / ?	3	4	3	4	2	3	3	12
N2-2627T	RM2	Mehrgarh (MR3T-S36)	15-17 yr / ?	3	4	2	3	2	3	2	10
U1-3412	RM1	Mahadaha (MDH-2)	17-20 yr / Male	3	2	5	8	6	7	6	27
U2-3512	RM2	Mahadaha (MDH-2)	17-20 yr / Male	6	2	5	6	6	5	5	22

Table 5.1. (Continued).

SPECIMEN NO.	MOLAR TYPE	PROVENIENCE	AGE/SEX	MOLNAR SCORE			SCOTT QUADRANT SCORES				
				Direction	Form	Degree	Quad 1	Quad 2	Quad 3	Quad 4	Total
V1-3612	RM1	Mahadaha (MDH-11)	18-23 yr / Male	3	2	4	6	5	6	3	20
V2-3711	RM2	Mahadaha (MDH-11)	18-23 yr / Male	3	3	3	5	3	6	3	17
W1-3812	LM1	Mahadaha (MDH-1)	18-21 yr / Male	3	3	3	5	3	4	3	15
W2-3911	LM2	Mahadaha (MDH-1)	18-21 yr / Male	1	4	2	3	2	3	3	11
X1-4022	RM1	Mahadaha (MDH-15)	20-25 yr / Male	3	3	4	6	5	6	5	22
X2-4113	RM2	Mahadaha (MDH-15)	20-25 yr / Male	3	3	3	5	3	4	4	16
Y1-4311	RM1	Mahadaha (MDH-26)	19-21 yr / Male	3	2	5	6	6	6	5	23
Y2-4412	RM2	Mahadaha (MDH-26)	19-21 yr / Male	5	2	2	4	4	4	4	16
AA1-4511	RM1	Harappa (H87-145)	29 yr / Female	3	4	3	5	4	6	5	20
AA2-4611	RM2	Harappa (H87-145)	29 yr / Female	3	4	3	5	4	5	2	16
BB1-4711	RM1	Harappa (H88-191)	19 yr / Male	3	4	4	6	3	5	5	19
BB2-4811	RM2	Harappa (H88-191)	19 yr / Male	2	3	2	2	1	2	2	7
CC1-4911	RM1	Harappa (H88-200)	18 yr / Male	3	4	4	6	3	6	3	18
CC2-5011	RM2	Harappa (H88-200)	18 yr / Male	2	3	2	3	1	3	2	9
DD1	LM1	Harappa (H88-200)	18 yr / Male	3	4	4	6	3	6	3	18
EE1-5211	RM1	Harappa (H88-197)	25 yr / Female	3	4	4	6	3	6	3	18
EE2-5311	RM2	Harappa (H88-197)	25 yr / Female	3	4	3	5	3	5	3	16
FF1	LM1	Harappa (H88-197)	25 yr / Female	3	4	4	6	3	6	3	18
FF2	LM2	Harappa (H88-197)	25 yr / Female	3	4	3	6	3	5	2	16

Mahadaha

MDH-1

Occlusal attrition of the first mandibular left molar (MDH 1 W1) of this young adult male has resulted in an oblique lingual to buccal (lingual-buccal)[1] wear plane in which the wear form is only partially concave. The moderate degree of wear on this tooth (Molnar score = 3; Scott score = 15) has only partly obliterated the cusp pattern, leaving lingual cusps 2 and 4 relatively intact. Lingual cusp 2 (metaconid) has been affected least by wear and it retains much of its original height. The moderate amount of wear on the buccal cusps has occurred to a greater degree on cusp 5 (hypoconulid) to the extent that the "Y" pattern of the central groove has been partially obliterated. Cusp 1 (protoconid) exhibits considerable occlusal attrition with exposure of a small (1mm x 2mm) dentinal pit, and two small Phase I shearing facets on the buccal-occlusal margin and a Phase II grinding facet (Hiiemae and Kay 1972) near the buccal edge of the dentinal pit (Figure 5.1). Both Phase I and II wear facets are also located on the occlusal surface of cusp 3 (hypoconid).

The micrograph illustrated in Figure 5.2 (3814) is a high magnification image (field) of facet 1 on the protoconid of the first molar. This facet has a convex surface that is tilted cervically in a distobuccal direction. The general area of high magnification analysis (Figure 5.1) is positioned in a buccal direction from an area of dentine exposure and postmortem damage, and near the buccal-occlusal margin of the tooth surface. In general, the enamel fabric of this specimen is somewhat rough. Many long fine scratches are visible, several of which are truncated by the margins of the field. Generally, the finer of these scratches exhibit sharp margins, while several of the wider scratches also possess rounded margins. The troughs of all scratches appear relatively smooth. Several small pits

[1] A hyphen is used to separate the names of two tooth surfaces, when reference is made to a specific position on the tooth surface or to the orientation of an occlusal wear plane. However, the conventions of dental anatomy are followed when reference is made to dental crown diameters (e.g. mesiodistal rather than mesial-distal).

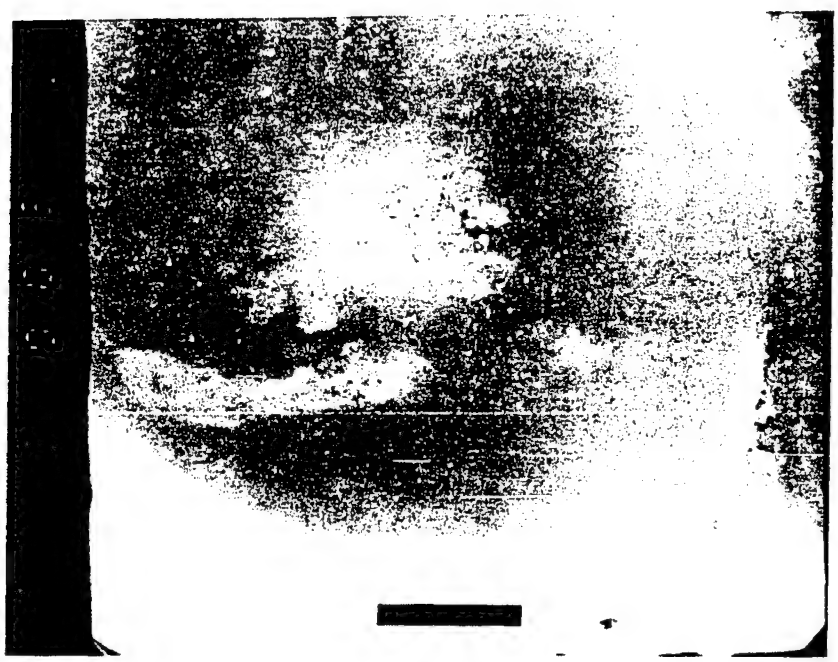


Figure 5.1. Low Magnification (20x) Micrograph of Cusp 1 from MDH-1-W1, Field 3801. Scale equals 1000 microns.

are also visible at the upper left and lower right corners of the field. All but three or four of these scratches are oriented vertically or slightly transversely in the micrograph. This corresponds to an approximately buccomesial orientation on the facet surface, although some scratches have a very slightly distomesial orientation, respectively. The very fine and sinuous linear features visible at the center of the field are cracks attributable to postmortem damage to the tooth. The large oval-shaped object at far left in the micrograph is an artifact attributable to a defect in the micrograph negative. The microwear features are graphically depicted in an acetate transparency of normal field 3812 (Figure 5.3). An additional micrograph of an adjacent field (not illustrated) on facet 1 also reveals a preponderance of distobuccal-mesiolingually oriented scratches.

A natural form remains for both the wear plane and the occlusal surface of the second mandibular left molar of individual MDH 1 (W2), due to the slight degree of attrition (Molnar score = 2; Scott score = 11). Lingual cusps 2 and 4 show little wear, although the wear on cusp 4 is to such a degree that the medial ridge on the buccal side of the cusp has been obliterated. Buccal cusps 1 and 3 show the greater amount of wear, of course, with Phase I and Phase II facets present. Cusp 3 possesses two Phase I facets, one of which is distal to the moderate sized buccal pit, and an adjacent one which extends distally and lingually along the occlusal margin.

Figure 5.4 (3913) is a high-magnification view of the surface of the Phase I shearing facet (facet 1) on cusp 1 of the second lower left molar. The facet which is adjacent mesially to the buccal pit possesses a planar to concave surface and is sloped cervically toward the distal surface. The field shown is adjacent to the mesiolingual margin of the facet (to the right in micrograph) where it contacts the occlusal surface of the tooth (actually a ridge, on the original occlusal surface, separating facet 1 from a second Phase I facet (facet 2) located mesially). Visible are many long wide scratches that are oriented roughly buccolingually (top to bottom, respectively) in the micrograph, although with a

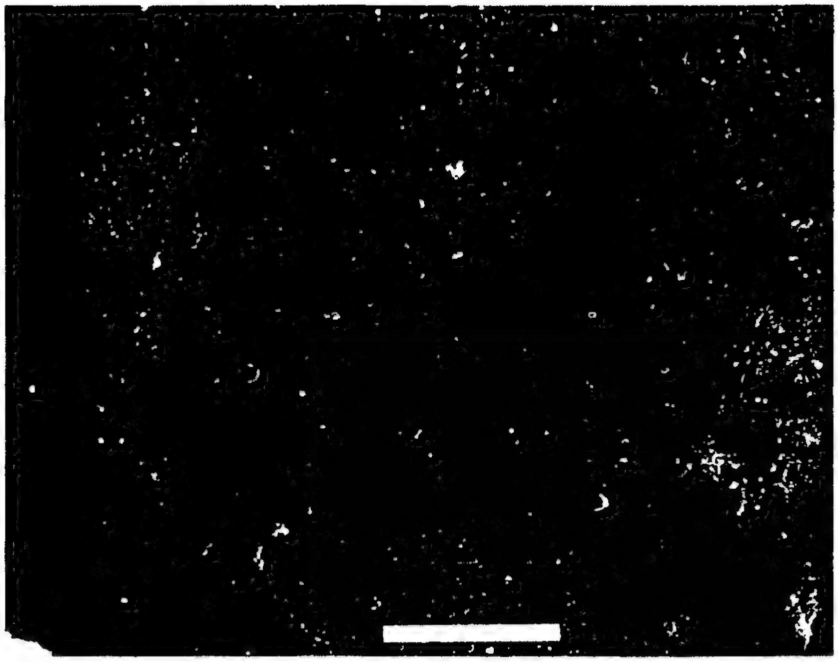


Figure 5.2. High Magnification (500x) Micrograph of Facet 1from MDH-1-W1, Field 3814. Scale equals 50 microns.

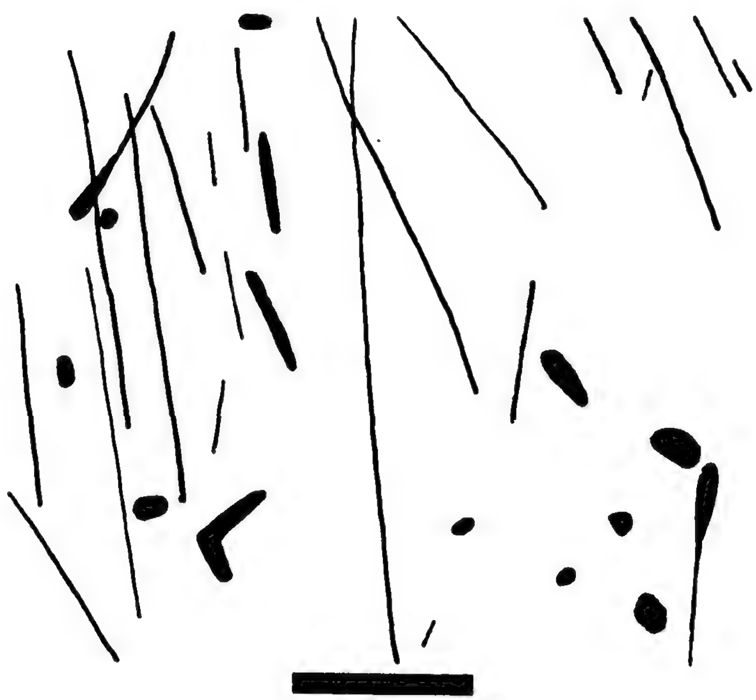


Figure 5.3. Acetate Transparency of 500x Field 3812. Scale equals 50 microns.

very slightly mesiodistal component, respectively (Figure 5.5). Generally, these scratches exhibit rounded and rough margins, smooth troughs, and slightly rough sides. Several scratches at the lingual edge of the facet (to the right side of the field) are oriented approximately in a mesiodistal direction (right to left, respectively, across the field), and these possess slightly sharper margins. As with the first molar of this specimen, most of the scratches on this facet are truncated by the field margins. In addition, examination of a second field adjacent several hundred micrometers buccally and distally to that illustrated also reveals several scratches with a buccolingual orientation. In general, this specimen exhibits a rough-textured enamel fabric, with a microwear pattern in which long scratches are crisscrossed by many shorter (and possibly older) scratches.

MDH-2

The occlusal surface on the first right mandibular molar of this young adult male (MDH 2 U1) possesses an oblique wear plane that faces buccally. The form of the wear is relatively flat, but slight rounding exists in a buccolingual direction, with the central groove area forming a convex ridge that is slightly elevated above the buccal and occlusal margins. The occlusal attrition is fairly advanced (Molnar score = 5; Scott score = 27) with the cusp pattern completely obliterated and replaced by large patches of exposed dentine, as illustrated in a drawing of the RM_1 and RM_2 from this individual (Figure 5.6, stippled area). In fact, the dentine exposure on the buccal quadrants has coalesced to form a shallow lake of dentine across both cusps 1 and 3, extending lingually to encompass cusp 5. The severe attrition has obliterated most of the groove pattern on the occlusal surface, with only vestiges of the central groove and lingual portion of the transverse groove (oriented vertically in illustration) remaining near cusp 4 (entoconid). A moderate to large buccal pit is also present in this specimen.

The specimen is so severely worn that both Phase I shearing facets on the

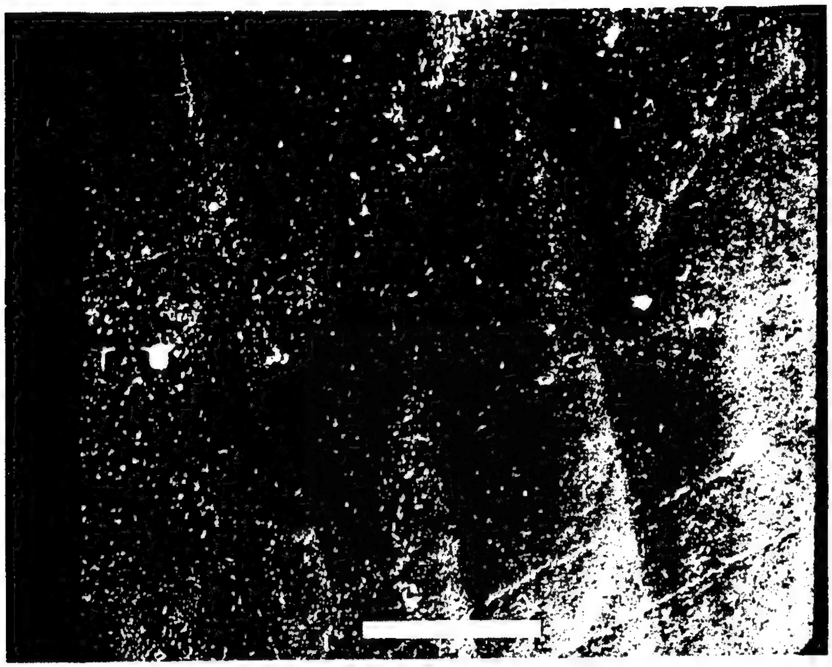


Figure 5.4. High Magnification (500x) Micrograph of Facet 1from MDH-1-W2, Field 3913. Scale equals 50 microns.

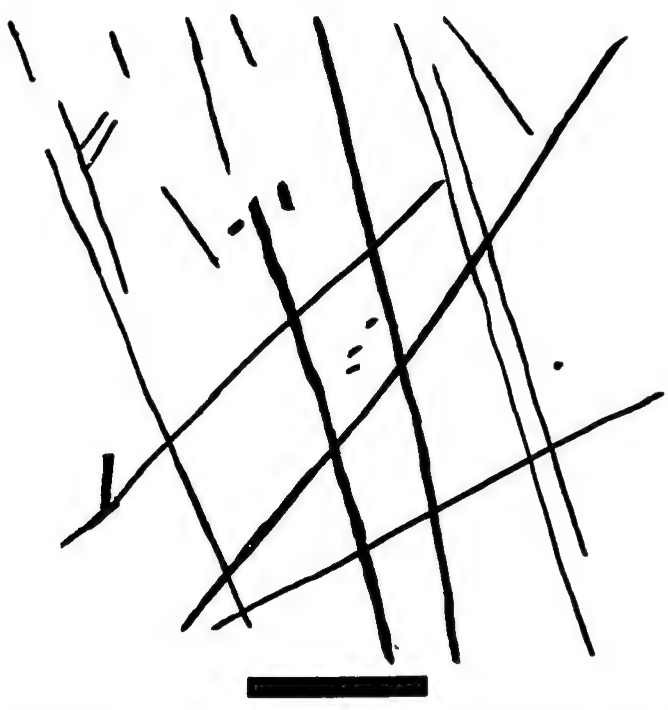
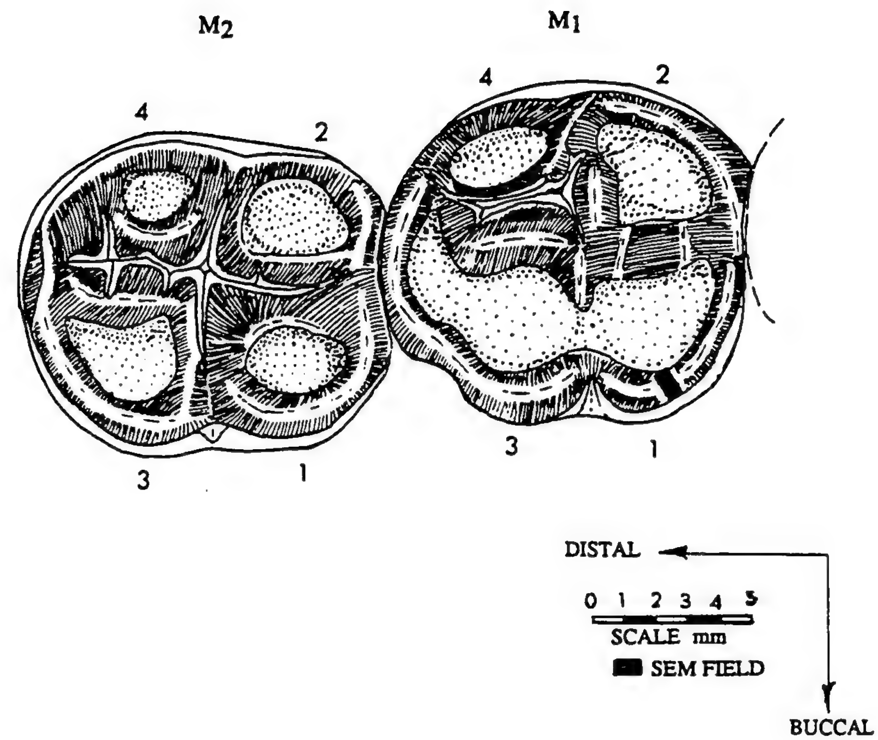


Figure 5.5. Acetate Transparency of 500x Field 3911. Scale equals 50 microns.

a



b

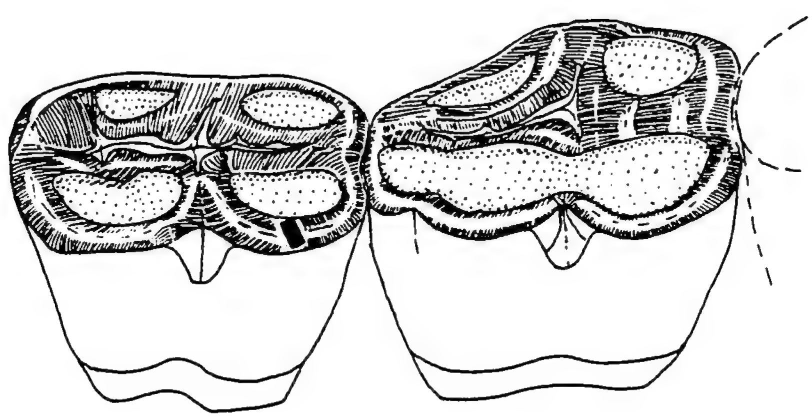


Figure 5.6. Drawing of RM_1 and RM_2 from Specimens MDH-2-U1/U2. Blackened Rectangles on Wear Facets Represent Position of SEM Fields. a: Occlusal Aspect. b: Buccal Aspect with 80 degree Lingualward Rotation.

protoconid have been united by a continuous convex ridge of enamel at the buccal-occlusal margin (Figure 5.6; also Figure 2b from Lukacs and Hemphill 1992). Figure 5.7 illustrates a high-magnification field (3414, Figure 5.6, darkened rectangular area) on the wear ridge between the occlusal and buccal surfaces of the molar in a position adjacent to the area of the wear ridge that angles cervically toward the large dentine lake described above. Three long narrow scratches at the center of the micrograph and several shorter ones at the upper left are oriented transversely from lower left to upper right (mesial to distal, respectively, with a slightly buccolingual component) across the field. Another short scratch is barely visible in the upper one-third of the field oriented roughly mesiobuccal-distolingual (left to right, respectively, in Figure 5.7). These features do not appear to be truncated by the field margins. An acetate transparency of normal field 3412 (Figure 5.8) illustrates the microwear features. In general, scratches possess relatively smooth troughs and predominantly rounded margins, while sharp margins occur infrequently. In addition, three or four small pits are visible in the micrograph, although another with very sharp edges is probably an artifact of the casting process (Gordon 1984c). Several long thin postmortem cracks plus detritus (possibly calcium carbonate deposits) are also visible. The smooth polished appearance of the enamel fabric suggests that this specimen may be an outlier, when it is compared with the other Mahadaha molar specimens. An additional field (not illustrated) taken several hundred micrometers distal to that in Figure 5.7 has a similar microwear pattern, with several long thin and one shorter and wider mesiodistal oriented scratches present. A single long buccolingually oriented scratch is also visible in this field.

The second right mandibular molar of MDH-2 (U2) has a horizontal wear plane with a relatively flat form of wear. The degree of wear is similar to the first molar, although dentinal patches have not coalesced on this specimen (Figure 5.6) (Molnar score = 5; Scott score = 22). The morphology of all cusps has been obliterated and replaced by

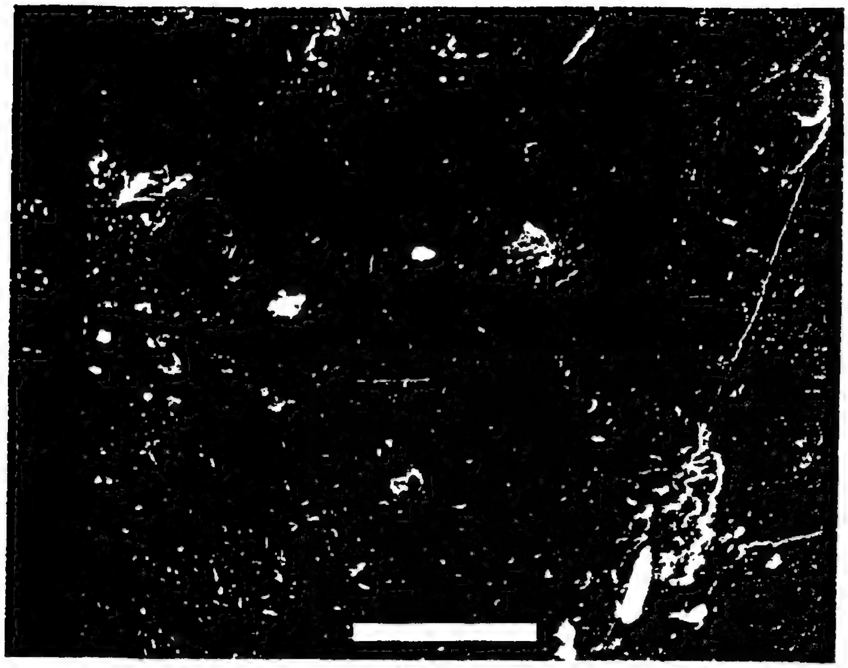


Figure 5.7. High Magnification (500x) Micrograph of Facet 1 from MDH-2-U1, Field 3414. Scale equals 50 microns.

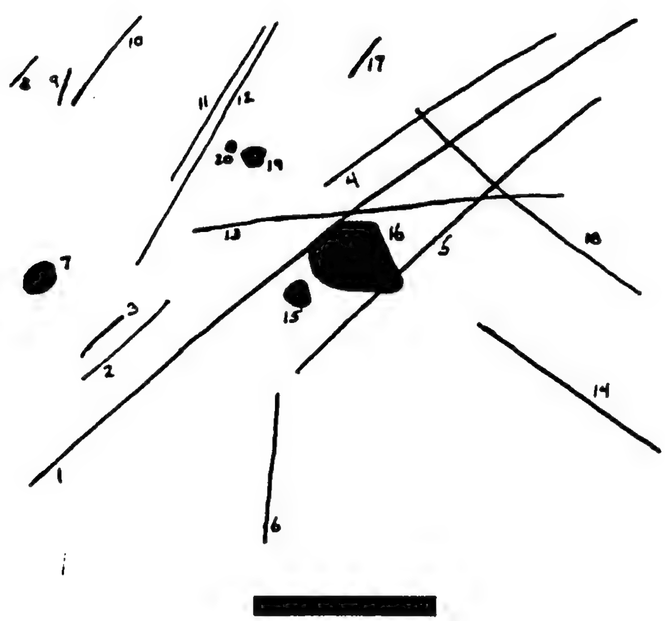


Figure 5.8. Acetate Transparency of 500x Field 3412. Scale equals 50 microns.

these patches of dentine exposure. Unlike the first molar, attrition has not been severe enough to obliterate the groove pattern, with only the extreme buccal and lingual portions of the transverse sulcus removed by wear. The buccal pit is also moderately large, although slightly smaller than in the first molar.

This specimen also possesses no wear facets, but instead exhibits a wide ridge or platform of enamel with a convex surface at the slope between the occlusal and buccal surfaces. Figure 5.6 (also Figure 2b from Lukacs and Hemphill 1992) illustrates the portion of this wear ridge, in the approximate position of the original facet 1, that was assessed at high magnification. Many long narrow and several long wide scratches are visible in the micrograph (3514) of this area on the wear ridge (Figure 5.9). Most of these features are oriented transversely from a mesial direction toward a distal direction (from the lower left to upper right corners in micrograph). A single long wide truncated scratch is visible in the upper portion of Figure 5.9 and possesses more of a mesiobuccal-distolingual component to its orientation. A short wide vertical scratch visible at the far right and two fine vertical scratches at the lower left have roughly distobuccal-mesiolingual orientations. The features are also illustrated in the acetate transparency produced from normal field 3512 (Figure 5.10). These scratches generally possess rough troughs and sides, and rounded but somewhat rough margins. The slope between the occlusal and buccal surfaces on this cusp is beyond the left margin of the illustration. Also, several large dust particles and some caliche deposits are visible in the lower right quadrant of the micrograph. An additional high magnification field (not illustrated) also reveals several long fine scratches with orientations identical to those described for Figure 5.9. In contrast with the first molar, the enamel fabric of specimen MDH 2 U2 is rather rough-textured, with long scratches crisscrossing shorter ones.

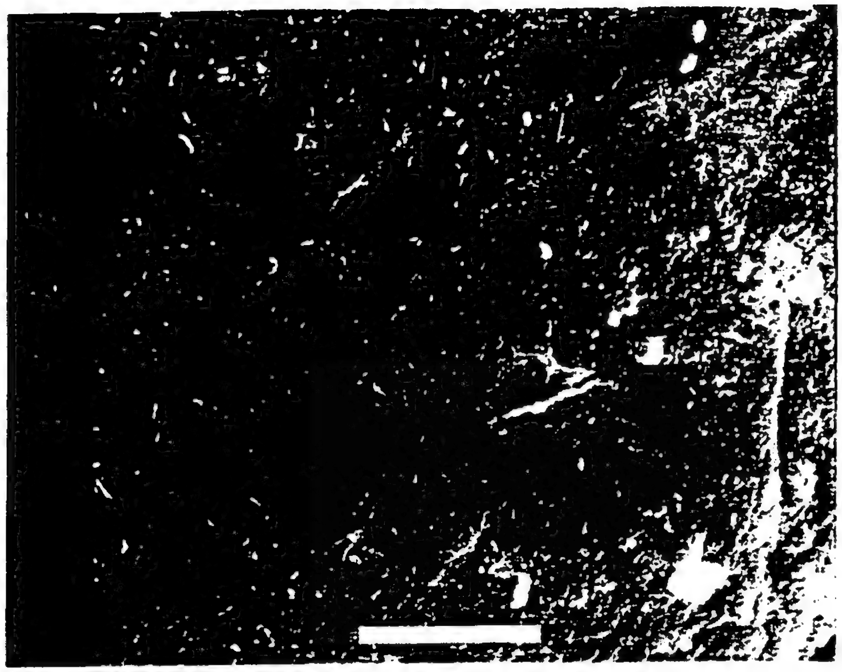


Figure 5.9. High Magnification (500x) Micrograph of Facet 1 from MDH-2-U2, Field 3514. Scale equals 50 microns.

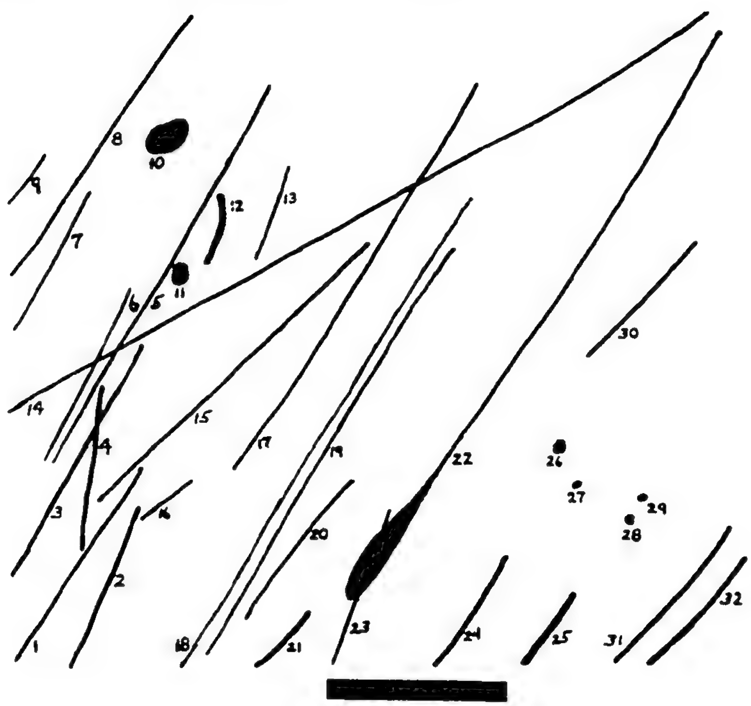


Figure 5.10. Acetate Transparency of 500x Field 3512. Scale equals 50 microns.

MDH-11

An oblique buccal facing wear plane occurs on the occlusal surface of the first mandibular right molar (MDH 11 V1) of this young adult male. The wear form of the occlusal surface can be characterized as one-half cupped, and the degree of wear is moderately severe (Molnar score = 4; Scott score = 20). The lingual cusps retain much of their original height, but attrition has exposed a small dentinal patch on each quadrant. Vestiges of the central groove and the lingual portion of the transverse groove remain, as well as the distolingual groove between cusps 4 and 5. Crowns of the buccal cusps have been obliterated by attrition for the most part, with large patches of dentine exposure on both quadrants. The dentine patch on cusp 3 has coalesced with a smaller one on cusp 5 to form a dentine lake. Also, much of the buccal portion of the transverse groove and parts of the central groove on the buccal quadrants have been lost due to wear. In addition, well-developed Phase I wear facets have formed at the occlusal margin of both buccal quadrants, adjacent to the moderate sized buccal pit. The Phase II facets have been obliterated by the dentine exposure on these quadrants.

The Phase I facet (facet 1) selected for analysis is present along the mesial side of the buccal pit and transverse sulcus, and it is angled cervically in a distobuccal direction. A few wide distobuccal-mesiolingually oriented scratches observed at low magnification (10x) are also visible in the moderately tilted (15 degrees) high magnification field on the facet (3614, Figure 5.11). These features, as well as several very fine scratches, are oriented transversely from the upper left to the lower right, respectively. In addition, several medium pits are apparent in the lower right quadrant of the field. Several other much finer and shorter scratches oriented mesiobuccal-distolingually are roughly perpendicular to the broader scratches. These features are also depicted in the acetate transparency from this field (Figure 5.12). In general, the scratches have rounded margins

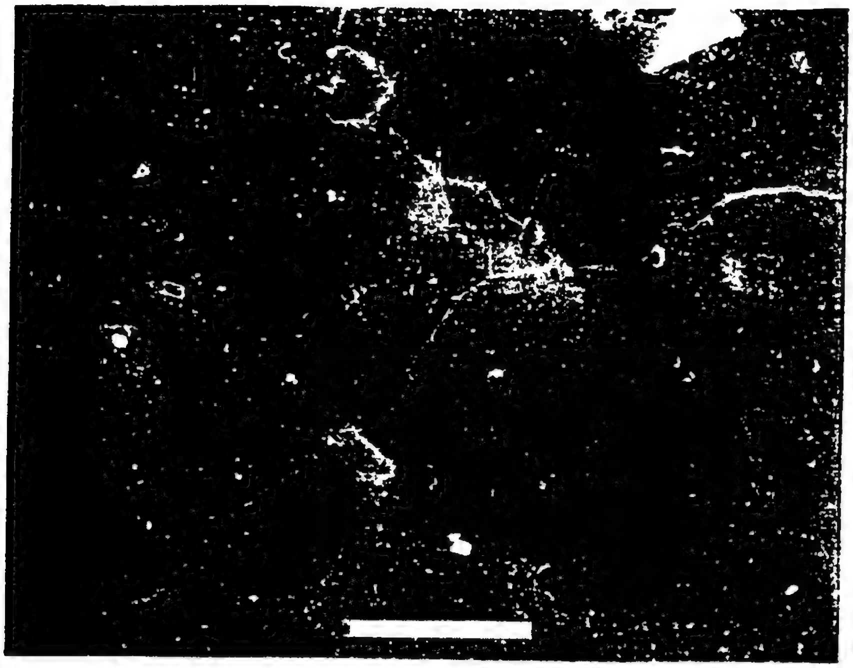


Figure 5.11. High Magnification (500x) Micrograph of Facet 1 from MDH-11-V1, Field 3614. Scale equals 50 microns.

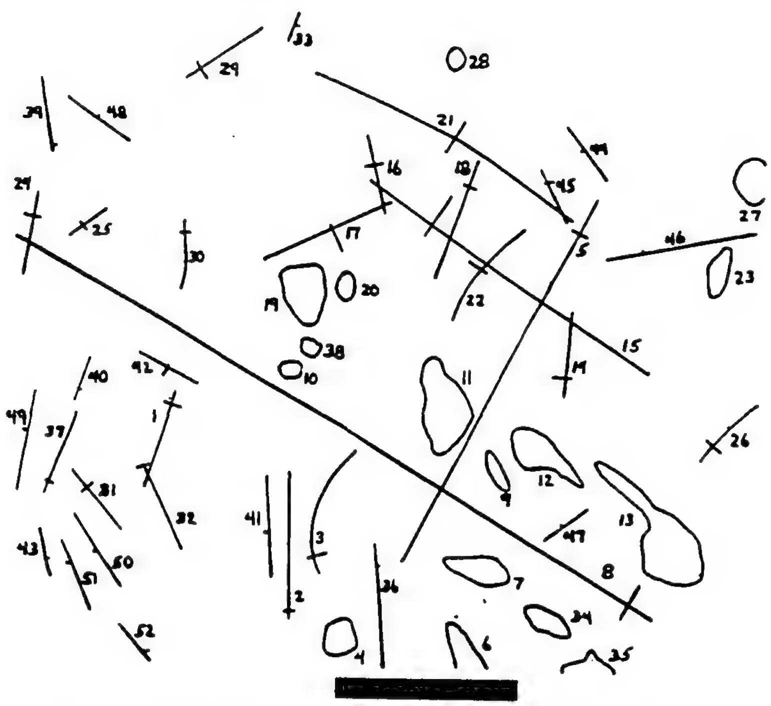


Figure 5.12. Acetate Transparency of 500x Field 3612. Scale equals 50 microns.

and smooth troughs, but some of the fine scratches have sharper margins. Several very fine scratches, with various orientations, and two small pits visible only in tilted field 3614 were added to the unmeasured count category. Artifacts visible in the micrograph include two jagged postmortem cracks and a dark vertical line at the far right, which is a shadow produced by the instrument. The concurrence of these microwear features with those visible in another field (not illustrated) adjacent lingually and several hundred micrometers distally is quite good, although the mesiobuccal-distolingually oriented scratches are more numerous than the distobuccal-mesiolingually oriented ones.

Overall, the features observed on this specimen are less visible than those on the second molar of this individual (described below) or on the other Mahadaha specimens. This may be attributable to the generally poor detail of micrographs from both the normal and tilted fields, which in turn may be due to casting defects during the replication process. Neither replication of the tooth surface by the casting process nor the focus of the instrument are implicated, as evidenced by the sharp edges of the postmortem cracks in the micrograph (Figure 5.11). However, close examination of Figure 5.11 reveals a large area of very tiny (< 1μm) bubble artifacts along the left lower margin of the micrograph, which probably obscure some of the detail of fine microwear features, predominantly narrow scratches.

The second lower right molar of MDH-11 (MDH 11 V2) also possesses an oblique buccal facing wear plane with a partially concave form of wear on the occlusal surface. The tooth is moderately worn (Molnar score = 3: Scott score = 17):the lingual cusps 2 and 4 retain much of their original height and morphology, but the medial ridge on the buccal surface of cusp 4 has been worn away along with the distal portion of the central sulcus. Most of the original height and form of buccal cusps 1 and 3 have been removed by attrition. A small patch of dentine exposure occurs on cusp 1, whereas the larger amount of enamel removed from cusp 3 has resulted in a greater degree of dentine exposure. The

degree of wear on these buccal cusps has obliterated part of the buccal pit and the buccal portion of the transverse sulcus, as well as producing well-formed Phase I facets. Two are found on either side of the buccal pit, and another is located along the mesiobuccal margin of cusp 1 and curves lingually. Phase II grinding facets are also preserved on enamel ridges near the buccal margins of the dentinal patches.

The Phase I facet (facet 1) is adjacent mesially to the buccal pit and transverse sulcus. This facet possesses a wide planar to concave surface and is tilted cervically toward the buccal surface at a shallow angle. Figure 5.13 represents a high-magnification and moderately tilted field (3713, 15 degrees) at the extreme mesiobuccal corner of the facet. The light triangular area at the lower left is part of the ridge of enamel on the occlusal surface that is adjacent to the mesial edge of the facet. Many long narrow and some long but wider scratches are apparent, most of which possess a roughly buccolingual orientation (left to right, respectively), but some are more transversely oriented, such as the long wide mesiobuccal-distolingual scratch in the lower one-third of the illustration. The acetate transparency taken from normal field 3711 (Figure 5.14) graphically illustrates the microwear features. As is true for the other M_2's, many of the scratches exhibited by this specimen possess rough troughs and sides, as well as rounded but somewhat rough margins. Generally, a relatively rough-textured enamel fabric is present, but fewer crisscrossing of scratches is apparent than on other specimens. An irregularly shaped white object in the upper center of the illustration is a dust particle or other artifact on the surface of the dental replica. The long sinuous crack traversing the center of the micrograph is due to postmortem deterioration of the original specimen. The field illustrated appears to be representative of the type of features and orientations present on the facet, since an additional field located several hundred micrometers mesially and lingually exhibits a similar pattern of microwear.

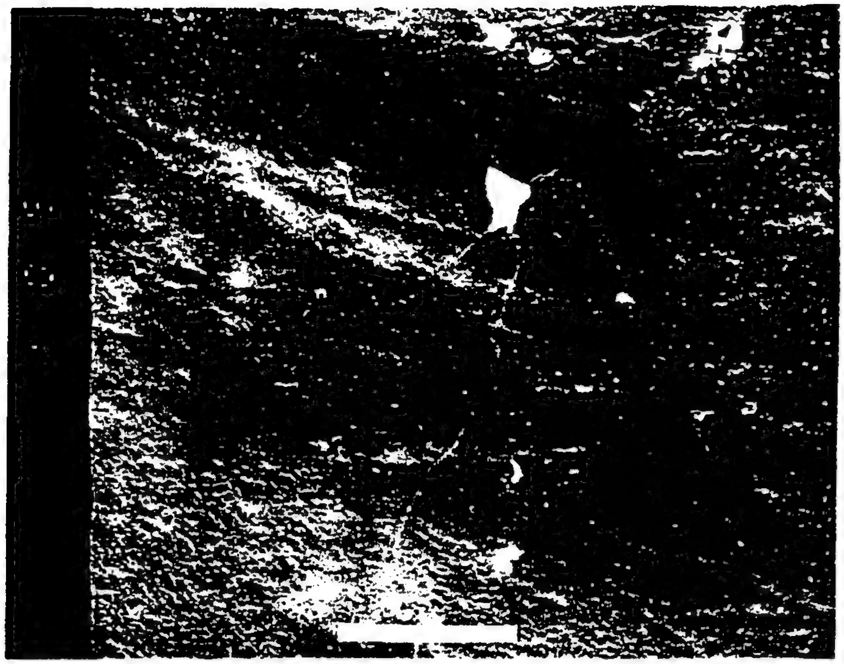


Figure 5.13. High Magnification (500x) Micrograph of Facet 1 from MDH-11-V2, Field 3713. Scale equals 50 microns.

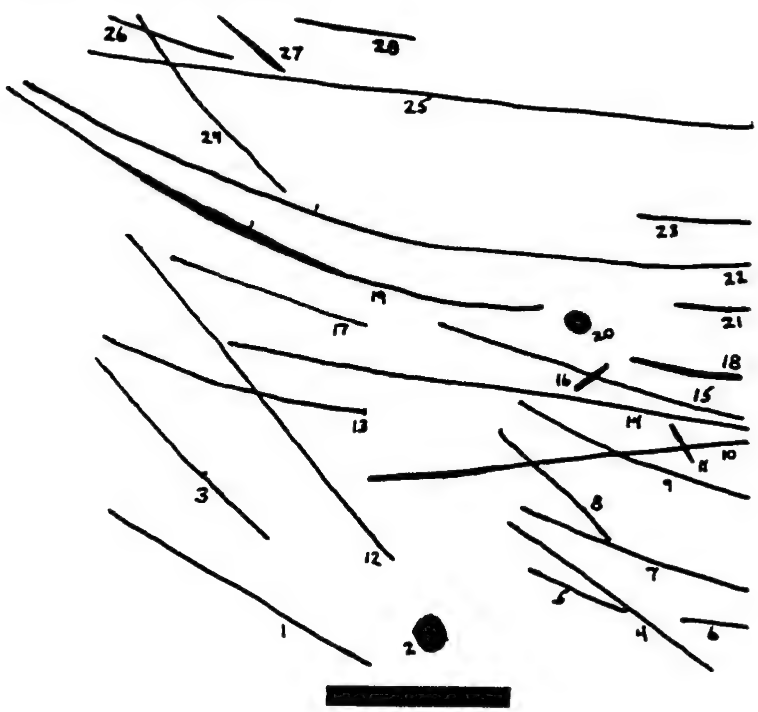


Figure 5.14. Acetate Transparency of 500x Field 3711. Scale equals 50 microns.

MDH-15

The first right mandibular molar of this adult male (MDH 15 X1) possesses an oblique buccal facing wear plane, but the occlusal surface also slopes distally with slight rounding present mesially on the mesial sides of cusps 1 and 2. One-half of the occlusal surface is cupped in a lingual to buccal direction, and the attrition is moderately severe (Molnar score = 4; Scott score = 22). Due to slightly less attrition, both mesial lobes are higher than those on the distal side, when measured from a plane drawn horizontally through the cervical line (cemento-enamel junction). Only cusp 2 has retained much of its original height, although the wear has obliterated most of the original cuspal morphology and produced a small dentinal pit. A slightly larger dentinal pit occurs on cusp 4, and vestiges of the mesial portion of the central sulcus and lingual portion of the transverse sulcus remain. Only two small segments of the buccal portion of the transverse sulcus remain between the buccal quadrants, lingually from the moderate sized buccal pit. In addition, a greater degree of wear in this region has resulted in exposure of two large dentine lakes, which take up much of the occlusal surface area of cusps 1 and 3 (Figure 5.15). The dentine lake on cusp 3 also extends lingually onto the mesial side of the occlusal surface. Although much of the buccal margin of the occlusal surface has been reduced to a wide rim of enamel, distinct Phase I and Phase II wear facets are still present on both buccal lobes.

Facet 2 was selected for the present microwear analysis, because the high magnification field from facet 1 (not illustrated), taken at the mesial edge of the buccal pit, revealed a considerable amount of postmortem damage to the occlusal surface of the tooth (Figure 5.15). However, the standardized protocol for orienting the specimen and facet within the instrument chamber was followed, and both facets exhibited similar types and orientations of microwear features. Facet 2 is located at the mesiobuccal corner of cusp 1

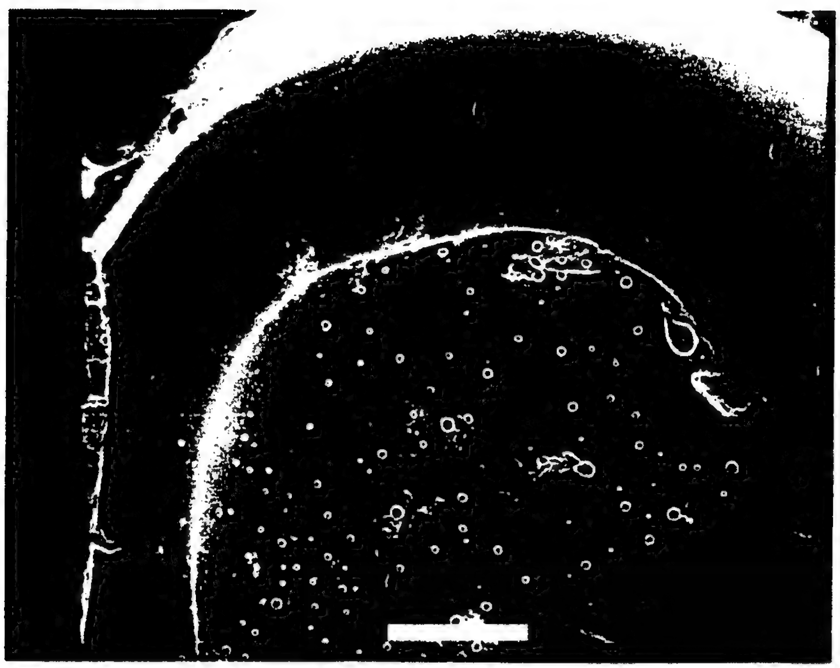


Figure 5.15. Low Magnification (20x) Micrograph of Cusp 1 from MDH-15-X1, Field 4003. Scale equals 1000 microns.

on a ridge of enamel that wraps lingually from the occlusal margin of the buccal side to the mesial side. The facet is roughly ovoid shaped with a generally planar surface except at the slope between the occlusal and buccal surfaces. The elongated surface also tilts upward at its mesial and distal ends, and the plane of the facet tilts very slightly toward the buccal and mesial surfaces. However, it should be noted that the field described below is located near the mesiolingual end of the facet, an area that may have been tilted somewhat differently and been closer to the electron collector of the SEM than the second field. This difference in collector geometry very likely has no bearing in the present analysis, but may be an important factor in the quantitative analysis of microwear from this facet (Gordon 1988).

Several prominent, wide, and mesiodistally oriented scratches, which may be due to postmortem damage, as well as some pitting and buccolingually oriented scratches were observed under low power light microscopy. The moderately tilted (15 degrees) high magnification field (4024, Figure 5.16) reveals a large number of scratches, with four or five orientations represented. Several scratches at both the upper right and the lower left corners have roughly the same transverse buccolingual orientation (from upper left to lower right, respectively). Several other long transverse scratches at the center, from the upper left corner to the lower right corner, are oriented in a more mesiobuccal-distolingual direction. Other fainter and more vertically oriented scratches, such as some short ones at the lower center, a long vertical scratch just left of the center, and another near the right margin have a more distobuccal-mesiolingual orientation (top to bottom, respectively). In general, these scratches all have a buccolingual component to their orientations, and a large number of them appear to be truncated by the field margins at this magnification. However, an experimental analysis of the facet surface at a lower magnification (150x) showed that most of these features did not extend beyond the margins of the higher magnification field. Also visible are several roughly horizontal scratches: two long fine scratches at the upper left, a short wide scratch or gouge at the upper right, two prominent

gouges to the right of the center, and a short fine scratch at far right center. These are all oriented approximately mesiodistal (from left to right, respectively). The features are also graphically depicted in the acetate transparency (Figure 5.17) taken from normal field 4022. The majority of scratches possess rounded margins, although several sharp-margined scratches are also present. Most scratches appear to have relatively smooth troughs. As with other specimens, a somewhat roughened or furrowed enamel fabric is apparent, as a result of the crisscossing of many scratches by others. Two long thin cracks and a sharp edged pit are probably due to postmortem damage to the original specimen.

An oblique buccal facing wear plane and partially concave wear form are also found on the second lower right molar of individual MDH-15 (MDH 15 X2). However, only a moderate degree of wear (Molnar score = 3; Scott score = 16) is present on this specimen. As with the first molar, only lingual cusp 2 has retained much of its original height and morphology, with the buccal facing medial ridge still intact. The other cusps have not been worn completely flat but nearly so. However, no dentine exposure is exhibited by either lingual cusp. The transverse and central grooves are nearly intact, although the distal portion of the latter groove is partially obliterated since it is cupped by the wear and is the lowest region on the occlusal surface. Two small patches of dentine have been exposed on cusps 1 and 3, due to the greater degree of wear on these quadrants. This additional wear has also obliterated the buccal portion of the transverse sulcus and part of the moderately large buccal pit. Two Phase I facets occur on each buccal quadrant near the buccal pit and along the buccal-occlusal margin. Phase II facets are also present near the dentinal patch on cusp 1 and on the large portion of cusp 3 that faces lingually.

The Phase I facet of present interest possesses a slightly convex surface that is tilted on its longitudinal axis in both a distal and buccal direction. The facet is located at the mesial edge of the transverse sulcus leading lingualward from the large buccal pit. The field of high magnification analysis is located approximately at the center of the facet and

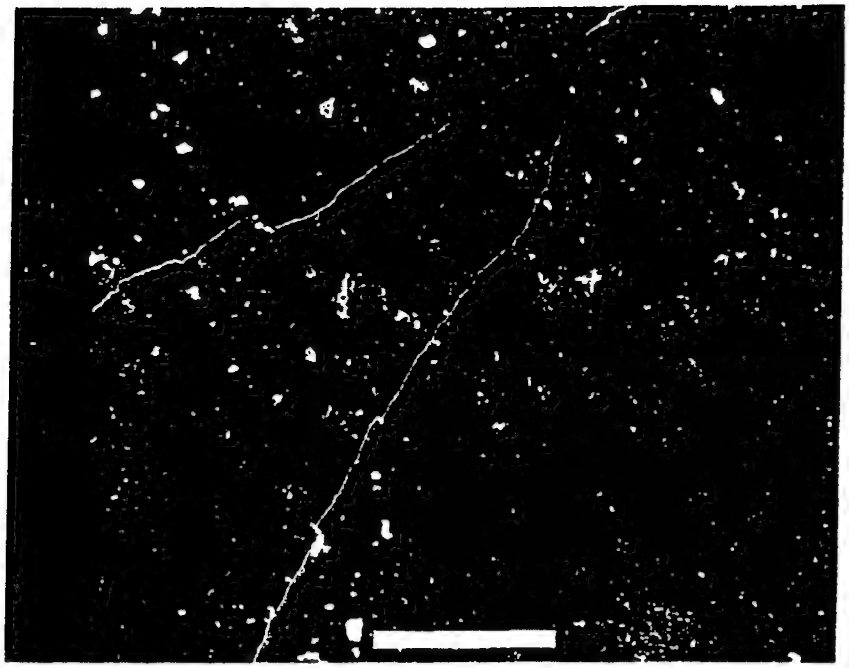


Figure 5.16. High Magnification (500x) Micrograph of Facet 2 from MDH-15-X1, Field 4024. Scale equals 50 microns.

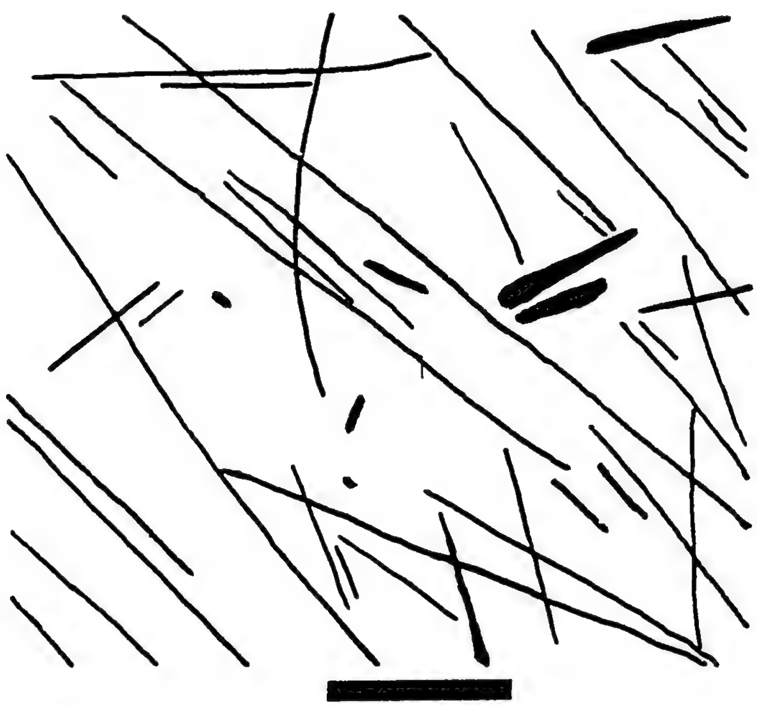


Figure 5.17. Acetate Transparency of 500x Field 4022. Scale equals 50 microns.

adjacent buccally to the break between this and another Phase I facet (facet 2). At low magnification, the light microscope revealed both buccolingually and mesiodistally oriented scratches. Some pitting was also observed adjacent mesially to the facet. The high magnification field (4113, Figure 5.18) reveals many long wide and some finer transverse scratches oriented in a mesiolingual-distobuccal direction (lower right to upper left, respectively). In fact, the direction of these features is roughly perpendicular to the specimen-collector axis and parallel to the tilt axis of the specimen stage, as is true for several of the other specimens. A few long narrow scratches faintly visible at the lower right and also the upper left corner are oriented approximately buccolingual (left to right, respectively). In general, many of the scratches observed in the illustration appear to be truncated by the field margins. The acetate transparency taken from the field further illustrates the microwear features (Figure 5.19). Morphologically, these scratches possess rough troughs and sides, and rough but rounded margins. The pattern of the enamel fabric is similar to that of specimen MDH 11 V2, in which a rough-textured enamel fabric, but less crisscrossing of scratches, is apparent.

The large bright angular artifacts at the lower left are possibly diagenetically produced calcium carbonate deposits. Two postmortem cracks in the tooth surface were too fine to be observed with the low power light microscope, but are visible in this high magnification view. An additional field (not illustrated) a few hundred micrometers mesial and buccal to the one described here reveals four or five long wide buccolingually oriented scratches, plus a large number of long fine and roughly mesiobuccal-distolingual scratches. This wide variance in scratch orientation from that observed in Figure 5.18 suggests that the latter field was actually taken from facet 2 instead of facet 1. However, there is still strong concurrence between the types of microwear features observed on these two adjacent Phase I facets.

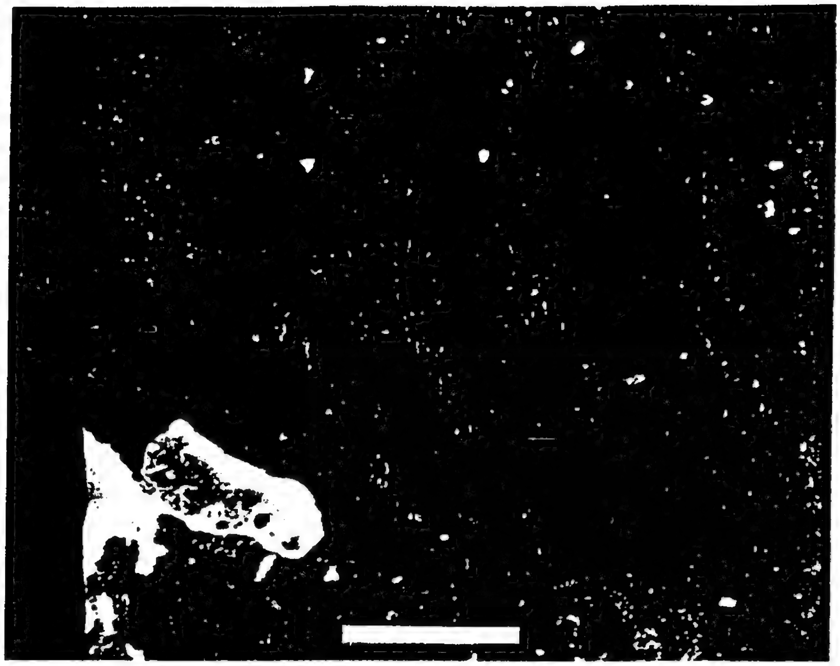


Figure 5.18. High Magnification (500x) Micrograph of Facet 1 from MDH-15-X2, Field 4113. Scale equals 50 microns.

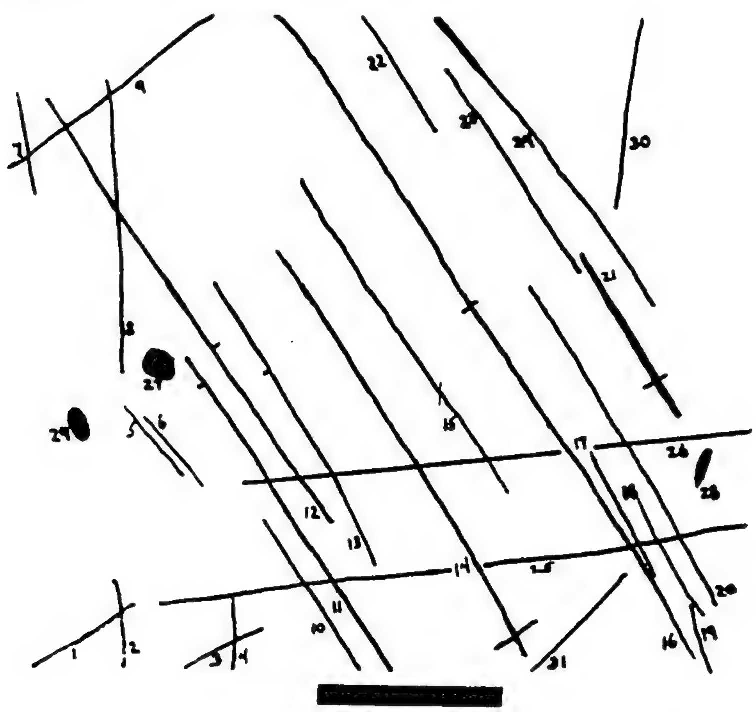


Figure 5.19. Acetate Transparency of 500x Field 4113. Scale equals 50 microns.

MDH-26

An unusual plane and form of occlusal wear is present in the first lower right molar (MDH 26 Y1) of this individual, with the oblique buccal facing occlusal plane also rounded in a mesiodistal direction. The severe attrition (Molnar score = 5; Scott score = 23) of all four quadrants has drastically reduced the height of the four cusps and obliterated the cuspal morphology. This specimen is unique in that it does not possess a hypoconulid (see Lukacs and Hemphill 1992). The unusual wear pattern, described above, has resulted in lingual cusp 2 remaining slightly higher than the other cusps. A large discrete patch of dentine is exposed on cusp 4 and a dentine lake occurs across large portions of the occlusal surface on the buccal and mesial lobes. Only vestiges of the transverse and central grooves are present on the distolingual lobe. The severe wear on the buccal lobes has produced a rim of enamel, wide on the hypoconid but thinner on the protoconid.

Facet 1 on the lower right molar of this individual actually can not be delineated as a true wear facet, due to the severe degree of attrition, but it is homologous with the Phase I facets on the other specimens. This area possesses a convex surface adjacent mesially to a large flat surface on the occlusal rim of the hypoconid which extends past the mesial side of the buccal pit and onto the protoconid. Also, a second Phase I facet (facet 2) is adjacent mesially to facet 1. The area of high magnification analysis is located approximately at the center of the facet and is adjacent buccally to a Phase II facet. Several long wide and a few narrower transverse scratches visible in the micrograph (4313, Figure 5.20), taken from a moderately tilted field (15 degrees), are oriented approximately buccolingually (upper left to lower right, respectively). However, a sharp edged buccolingual scratch at the upper left, and another at the center may be due to postmortem causes, rather than being true microwear features, and were not included with the measured features. Several additional scratches, of primarily narrow width, may be observed in a more vertical position in the illustration, with a more distobuccal-mesiolingual orientation (top to bottom, respectively).

Note that some of the shorter scratches are not truncated by the margins of the field. Several small to medium pits are also apparent in the micrograph, one of which is united with a scratch. These features are also graphically depicted in the acetate transparency from this field (Figure 5.21).

Morphologically, this field possesses more scratches with angular margins than the other specimen fields in the Mahadaha sample, although the margins of other scratches on this specimen are rounded. Most scratches possess relatively smooth troughs. In general, the enamel fabric is similar to that of other Mahadaha specimens in that a somewhat rough surface is present, with many long scratches crossing other short ones. An additional field located several hundred micrometers lingual and distal to that shown possesses a large number of similarly oriented scratches. A few mesiodistally oriented scratches and a larger number of pits were also observed in this adjacent field.

The oblique lingual facing wear plane and flat occlusal surface form are unique to the moderately worn (Molnar score = 2; Scott score = 16) second right molar of MDH-26 (MDH 26 Y2). This specimen is unusual since the wear has been more severe on the lingual lobes, leaving cusps 2 and 4 lower in height than buccal cusps 1 and 3. This unique macroscopic wear pattern may be associated with the 41 degree mesiobuccal (clockwise) torso-molar rotation of the tooth within the alveolus (Lukacs and Hemphill 1992). Much of the groove pattern is intact, with the exception of the distal portion of the central sulcus and the buccal portion of the transverse sulcus. A pinprick sized "dot" of dentine exposure on both cusps 1 and 4 may actually be noncarious pits (Scott 1979a), but the small size of the features and use of epoxy replicas limits differentiation under low power light microscopy. Wear facets are present but displaced on the occlusal surface, due to occlusion of the normally positioned RM^2 with this specimen. Several Phase I facets are located on both sides of the central sulcus near the mesial margins of cusps 1 and 2.

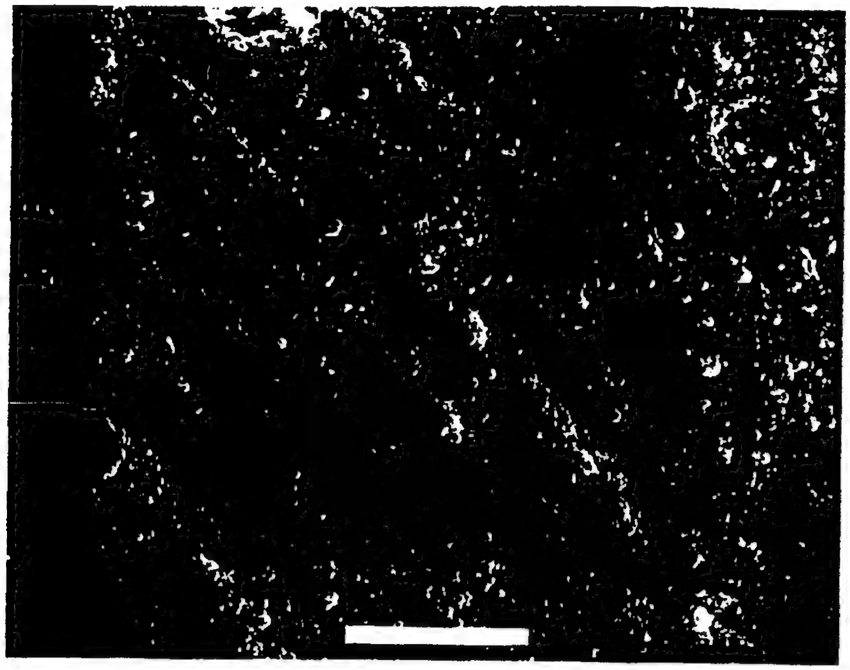


Figure 5.20. High Magnification (500x) Micrograph of Facet 1 from MDH-26-Y1, Field 4313. Scale equals 50 microns.

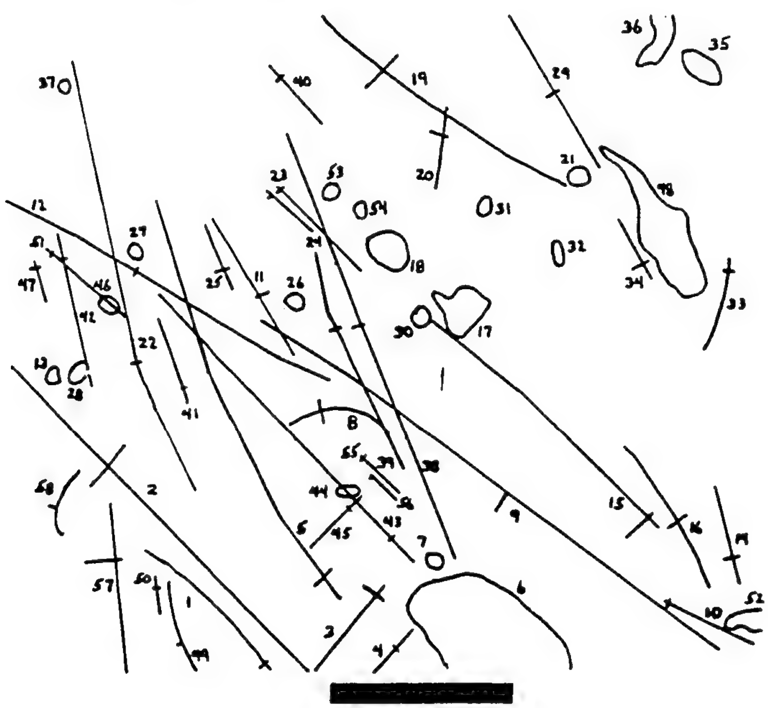


Figure 5.21. Acetate Transparency of 500x Field 4311. Scale equals 50 microns.

The Phase I facet selected for analysis is adjacent to a small pit on the mesial surface and to the mesial portion of the central sulcus. This facet is not truly homologous with those assessed on other specimens, but is sufficient for the present analysis because it is a functional Phase I facet. The facet possesses a planar surface that becomes strongly convex in a cervical direction, and the overall plane of the facet curves cervically toward the buccal and mesial surfaces. The high magnification field is located at the buccal margin of the facet and partially onto the convex slope between the occlusal and buccal surfaces. Some of the buccolingually oriented scratches observed on the facet surface at low magnification (not illustrated) are also apparent in the high magnification micrograph (4414, Figure 5.22) taken from a moderately tilted field (15 degrees). But several large and possibly postmortem pits seen at low magnification are not apparent in the micrograph.

The many long thin vertical scratches visible in the micrograph have a strong distomesial component to their orientation (top to bottom, respectively). The area of lighter contrast seen in the upper left corner indicates the cervically tilted surface of the facet at the occlusal-buccal margin of the molar. Four short thin transverse scratches at the right center of the illustration possess a distobuccal-mesiolingual orientation (upper right to lower left, respectively). Several small pits can also be seen at the lower left and upper right, some of which appear to be in unison with scratches. The features are graphically illustrated in the acetate transparency produced from the field (Figure 5.23). Also faintly apparent are many short fine scratches oriented mesiobuccal-distolingual (upper left to lower right, respectively). However, these features may actually reflect the underlying pattern formed by the microscopic enamel prisms, that were exposed as a result of the attrition to the tooth. But they also may be attributable to microwear turn-over, since Teaford (1988) has reported that microwear features can be renewed and reworked after periods as short as six to eight weeks. Alternatively, these differently oriented scratches may represent a previous type of wear pattern that was produced at an earlier age when the molar possessed a less

Figure 5.22. High Magnification (500x) Micrograph of Facet 1 from MDH-26-Y2, Field 4414. Scale equals 50 microns.

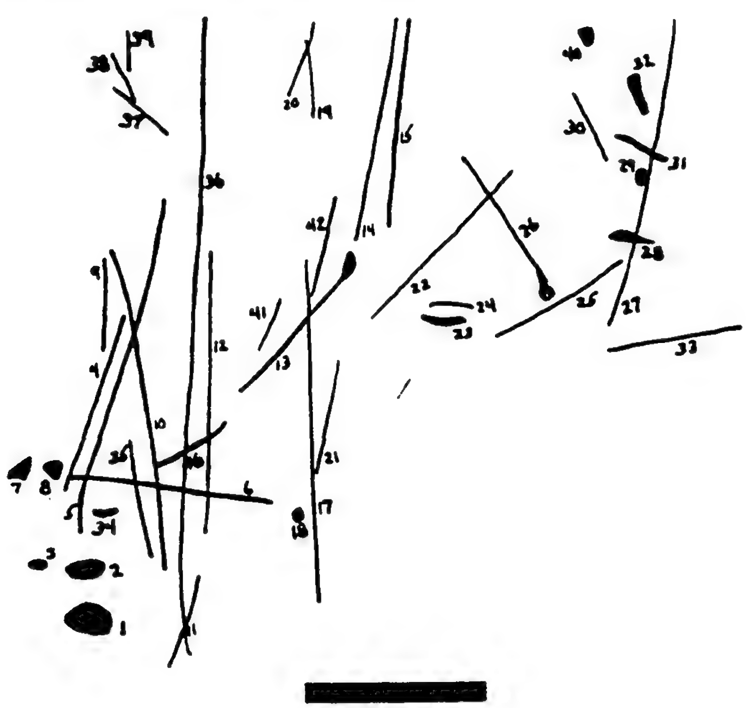


Figure 5.23. Acetate Transparency of 500x Field 4414. Scale equals 50 microns.

worn occlusal surface. The latter alternative seems more likely, because these scratches are oriented at right angles to the more prominent and presumably more recent scratches (see Chapter VII for further discussion). Overall, the scratches visible on this specimen field possess rough troughs and sides, with rough but rounded margins. However, the scratches are generally narrower than those exhibited on other specimen fields. As with several of the other specimens, this field shows a rough-textured enamel fabric with many crisscrossed short and long scratches.

The many bright angular particles observable at the right and upper left are artifacts, which are possibly diagenetically-produced calcium carbonate accretions on the surface of the facet. In addition, two postmortem cracks in the enamel are visible at the upper left. A second field taken several hundred micrometers in a lingual and mesial direction exhibits strong concurrence in the orientation of microwear features, although they are much less numerous.

Summary of Dental Attrition and Microwear

Generally, the lingual cusps of Mahadaha molars retain some of their original height in the more moderately worn teeth. The occlusal surfaces of more severely worn teeth possess a partially concave to flat form, and most frequently tilt in a plane toward the buccal surface. The degree of attrition on the Mahadaha lower molars is similar to other hunter-gatherer populations from North America, Europe and the Near East, in which the wear plane tilts buccally at a shallow angle. This pattern of attrition is consistent with a subsistence diet at Mahadaha of rough textured, fibrous, and abrasive foods (Misra and Pal 1980; Sharma et al. 1980; Smith 1984; Varma 1985, 1989).

In summary, the pattern of microscopic dental wear at Mahadaha may be characterized generally as a rough-textured enamel fabric overlain by many long fine and wide parallel scratches with rounded and relatively smooth margins, combined occasionally

with a few small pits (Table 5.2). Mahadaha second molars possess scratches that exhibit rounded but somewhat rough margins. The characteristic microscopic enamel fabric of Mahadaha molars resembles the furrowed weathered appearance of elephant skin, due to the crisscrossing of long and possibly more recent scratches by many shorter and possibly older scratches. This obliteration of scratches has been reported for other populations of prehistoric humans, fossil hominids, and extant primates (Harmon and Rose 1988; Teaford 1988b). Scratches on the Phase I facets are generally oriented parallel to the axis between the specimen and the instrument collector, and perpendicular to the axis upon which the facet plane is inclined. In addition, very worn Mahadaha teeth show greater variability in scratch orientation than more mildly worn specimens, perhaps because of slight lateral excursion of the mandible (see Chapter VII).

Mahadaha microwear shows a partial resemblance to that reported for a prehistoric population of Eskimo (Gordon 1986) and to precontact groups from islands off the Georgia-Florida coast (Teaford 1991), and from a functional dietary perspective to that reported for the relatively omnivorous chimpanzee. Gordon's study of Zuni and Eskimo dentitions revealed marked differences in microwear patterns between the two populations. The Eskimo, who consumed primarily marine mammals, exhibited microwear showing many fine scratches and very abundant small pits. Other differences noted are the relative proportions of pits and scratches, and relative orientations of scratches. However, feature densities were found to be fairly similar between the two populations. Although one of the characteristics of the Mahadaha microwear pattern is surface roughening, only a direct qualitative comparison of micrographs from each of these populations can reveal whether the enamel fabrics are truly similar. The precontact sites from the East Coast of the United States (St. Catherines Island) exhibited a greater number of pits and wider scratches than did the late contact sites from the same area (Teaford 1991). Qualitatively, the microwear pattern of the Mahadaha population resembles the precontact groups more than the later

Table 5.2. Summary of Qualitative Analyses of Dental Microwear

Archaeological Group	Microwear Pattern	Scratch Morphology	Enamel Fabric
MAHADAHA (Mesolithic)	Many long, fine and wide parallel and crisscrossed scratches; few andsmall pits.	Rounded and relatively smooth margins, with relatively smooth troughs and sides; minority of fields with angular sharp-margined scratches.	Rough textured enamel fabric, resembles elephant skin.
MEHRGARH (Neolithic) (Period 2, MR3)	High feature density with numerous narrow and medium scratches; few small to medium pits.	Inter-individual variability: smooth sharp margins with smooth sides and troughs; rough irregular and moderately rounded margins, and rough sides and troughs.	Major portions of shearing facets have very pitted and coarse surfaces; but polished enamel fabric on portions of facets and inter-facet occlusal surfaces.
MEHRGARH (Chalcolithic) (Period 3,MR2)	High feature density with variable microwear pattern; numerous long fine and wide scratches, some crisscrossed; abundant small and medium pits.	Sharp, rough and angular margins, with rough troughs; some fine scratches with rounded margins and smooth troughs.	Relatively smooth and polished enamel surface; M_2 shearing facets have a rough textured surface.

Table 5.2. (Continued).

Archaeological Group	Microwear Pattern	Scratch Morphology	Enamel Fabric
HARAPPA (Bronze-Age)	Moderately variable microwear pattern with long fine and wide scratches; moderate density of medium and large pits.	Scratch margins are partially smooth and rounded, but mostly rough and slightly irregular; most troughs are moderately rough, but some smooth-troughed scratches are present; no sharp-margined scratches present.	Smooth and polished surface; M_2 enamel fabric is rougher with greater number of crisscrossed scratches.

* This qualitative microwear summary is based on M_1's.

groups from the Georgia-Florida coast. Taken as a whole, the microwear pattern observed on the Mahadaha molars provides partial confirmation of the archaeological evidence for a hunting-gathering subsistence pattern at Mahadaha, with the inclusion of tough, fibrous and abrasive vegetable foods to a diet reliant upon undomesticated large mammals.

Neolithic Mehrgarh (MR3)

MR3-35

The occlusal surface on the first right lower molar (MR3 35 M) from this individual, a young female adult (Lukacs, unpublished catalog), exhibits moderately severe attrition (Molnar score = 4; Scott score = 16). An oblique lingual-buccal occlusal wear plane is present and the form of the occlusal surface is partially concave. The entire occlusal surface is worn, with cusps 1, 3 and 5 completely flattened and the lingual cusps much reduced in height. The majority of the occlusal morphology has been obliterated by the wear, including the buccal and central grooves. A relatively large patch of dentine is exposed on cusp 1, a smaller patch on cusp 3, and pinpricks of exposed dentine are present on cusps 2 and 4, and on the very prominent fifth cusp. Very prominent Phase I wear facets are present on the buccal cusps, although the Phase II facets are little more than convex platforms of worn enamel surrounding the exposed dentine. On cusp 1, facet 1 exhibits a planar to very slightly concave form and has an ovoid shape. Also on cusp 2, facet 2 is ellipsoid in shape and has a partially planar and also slightly convex surface. The ovoid facet 6, on cusp 3, exhibits a planar to very slightly concave surface form. An additional wear surface of polished enamel, located between facets 1 and 2, has a narrow hour-glass shape and a convex surface form.

Examination of the Phase I facets at low and high magnification revealed an unusually extensive and coarse pitted surface, with few or no scratches present. However, the polished enamel surface between facets 1 and 2 exhibits a high density of scratches and

more normal looking pits. Because this convex enamel surface is adjacent mesially to facet 1, it could be considered a part of this facet, but it was labelled as facet 4 in order to distinguish the micrographs. However, this area is not homologous with facet 4 from specimen MR2 46 J2 (cf. discussion below on chalcolithic Mehrgarh specimens). As with the neolithic Mehrgarh specimen MR3T S36 N2, the abnormal wear surfaces of the Phase I facets may be attributed to tooth-on-tooth wear, as a result of tooth-tooth contact near the end of the masticatory cycle (Teaford, personal communication 1993; Teaford and Runestad 1992). The resulting coarse surface damage could also have been exacerbated by the high enamel fluoride concentrations in the MR3 teeth (Lukacs et al. 1985), possibly in combination with postmortem diagenetic processes (cf. description below of abnormal microwear for specimen MR3T S36 N2).

Illustrated in Figure 5.24 is a high magnification micrograph (2449T) produced from a strongly tilted field (25 degrees), located on facet 4 immediately adjacent distally to facet 2, and at the upper (apical) end of the facet 4 band of enamel. A mesiobuccal-distolingual (lower left to upper right, respectively) orientation is predominant among the scratches present. Of these, several prominent medium-width scratches are present at the center of the field and numerous extremely fine scratches, parallel to the former, are present throughout the field. Other fine horizontal scratches are oriented buccolingually (left to right, respectively), while several fine and medium scratches, including the gouge at the far left, exhibit a distobuccal-mesiolingual orientation (upper left to lower right, respectively). Several small and medium pits are also present, but the large pit at upper center was not analyzed because its appearance suggested that it may be due to postmortem damage to the tooth. Similarly, several very tiny pits (funnel-shaped depressions) were not analyzed, because of their resemblance to bubble artifacts. The large white blotch at the lower field margin is a dust particle, while the dark patch in the upper left corner is caused by scuffing of the gold coating on the replica. The majority of microwear features are further illustrated

in an acetate transparency produced from normal field 2447T (Figure 5.25). As with other specimens, slight buccolingual foreshortening of tilted field 2449T revealed several additional scratches, concentrated at the lower right, which are not illustrated in Figure 5.25. These additional features were recorded under the unmeasured count category.

Morphologically, most of the fine scratches exhibit smooth sharp margins, and smooth sides and troughs, while rounded margins are also present on some narrow scratches. Medium-width scratches exhibit rough to very rough and rounded margins, with rough sides and troughs. The extremely high feature density characteristic of facet 4 may be due to the fact that this area of the occlusal surface is affected more by dietary constituents or contaminants than are the wear facets, as discussed previously. The general microwear pattern consists of a highly polished enamel fabric cut by numerous fine and several medium scratches, some of which are crisscrossed. As previously described, the enamel fabric of Phase I facets for this tooth have an extremely pitted and rough appearance, similar to eroded enamel, and they lack normal appearing microwear features.

MR3T-S36

Individual MR3T-S36 is a young adult, 15-17 years of age, based on unerupted maxillary and mandibular third molars (Lukacs, unpublished catalog). The sex is indeterminate. The slight to moderate occlusal attrition (Molnar score = 3; Scott score = 12) of the first right lower molar (MR3T S36 N1) from this individual has resulted in partial reduction in height of all cusps, except the metaconid (cusp 2) (Figure 5.26). Consequently, the latter cusp retains more of its natural morphology than the other cusps. Differentially occlusal wear has produced a partially concave occlusal surface form on the mesial half of the crown, while a completely concave form is present on the distal half. Consequently, the latter cusp retains more of its natural morphology than the other cusps.

Figure 5.24. High Magnification (500x) Micrograph of Facet 4 from MR3-35-M, Field 2449T. Scale equals 50 microns.

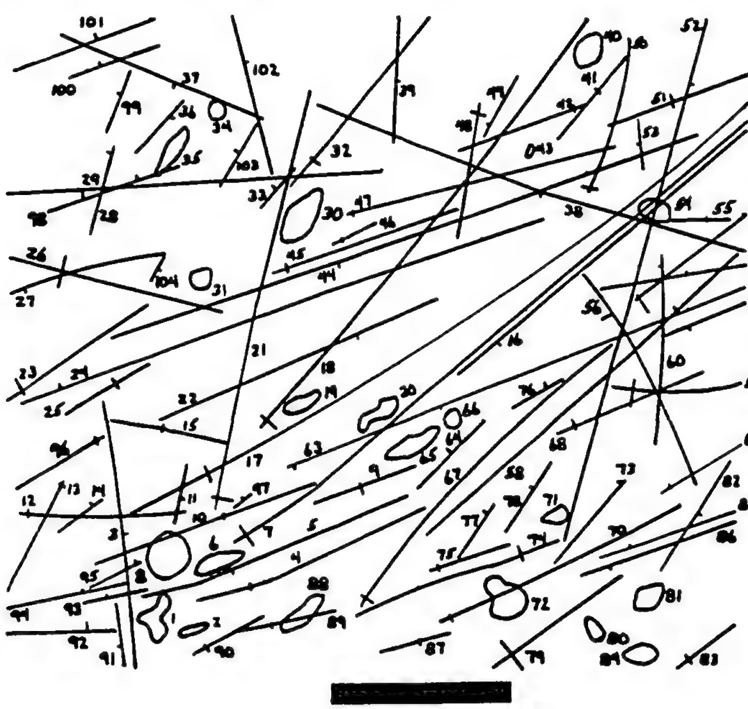


Figure 5.25. Acetate Transparency of 500x Field 2447T. Scale equals 50 microns.

Differentially occlusal wear has produced a partially concave occlusal surface form on the mesial half of the crown, while a completely concave form is present on the distal half. The oblique occlusal wear plane is orientated in a lingual-buccal direction. Although much of the occlusal morphology has been at least partially obliterated, the central and lingual grooves remain intact. This specimen is unusual in that it exhibits a prominent protostylid paramolar cusp on the mesiobuccal surface of cusp 1. A very tiny dentinal pit is exposed on the occlusal surface of cusp 1. Large Phase I wear facets are present on cusp 3 (facet 6) and cusp 4, while smaller ones are present on cusps 2 and 5. Although cusp 1 does not exhibit any true Phase I facets on the occlusal surface, a narrow band of wear wraps around the occlusal-buccal margin from the midline toward the mesial side of the tooth. A slightly convex area on this worn surface, homologous to facet 1, was selected for SEM analysis.

Illustrated in Figure 5.27 is a moderately tilted (15 degrees) high magnification field (2514) taken on the distal portion of cusp 1 near the occlusal-buccal margin (Figure 5.26a). Generally, the microwear pattern consists of many long fine scratches, which exhibit two primary orientations, as well as a few small pits and a single larger pit. These features are graphically depicted in an acetate transparency from normal field 2512 (Figure 5.28). Visible in the two illustrations are numerous long fine and medium-width scratches, which are oriented buccolingually (left to right, respectively). Other slightly transverse scratches exhibit a more mesiolingual-distobuccal orientation (lower right-upper left, respectively). Also present are several short fine scratches that exhibit a mesiodistal orientation (bottom to top, respectively), as well as several slightly longer and more transverse scratches. The scratch morphology consists predominantly of rough and irregular margins that are moderately rounded, although a few scratches exhibit sharp margins. Many scratches exhibit rough sides and troughs, while some smooth troughs and sides are present. The roughened appearance of the enamel fabric is partly due to the many crosscrossed

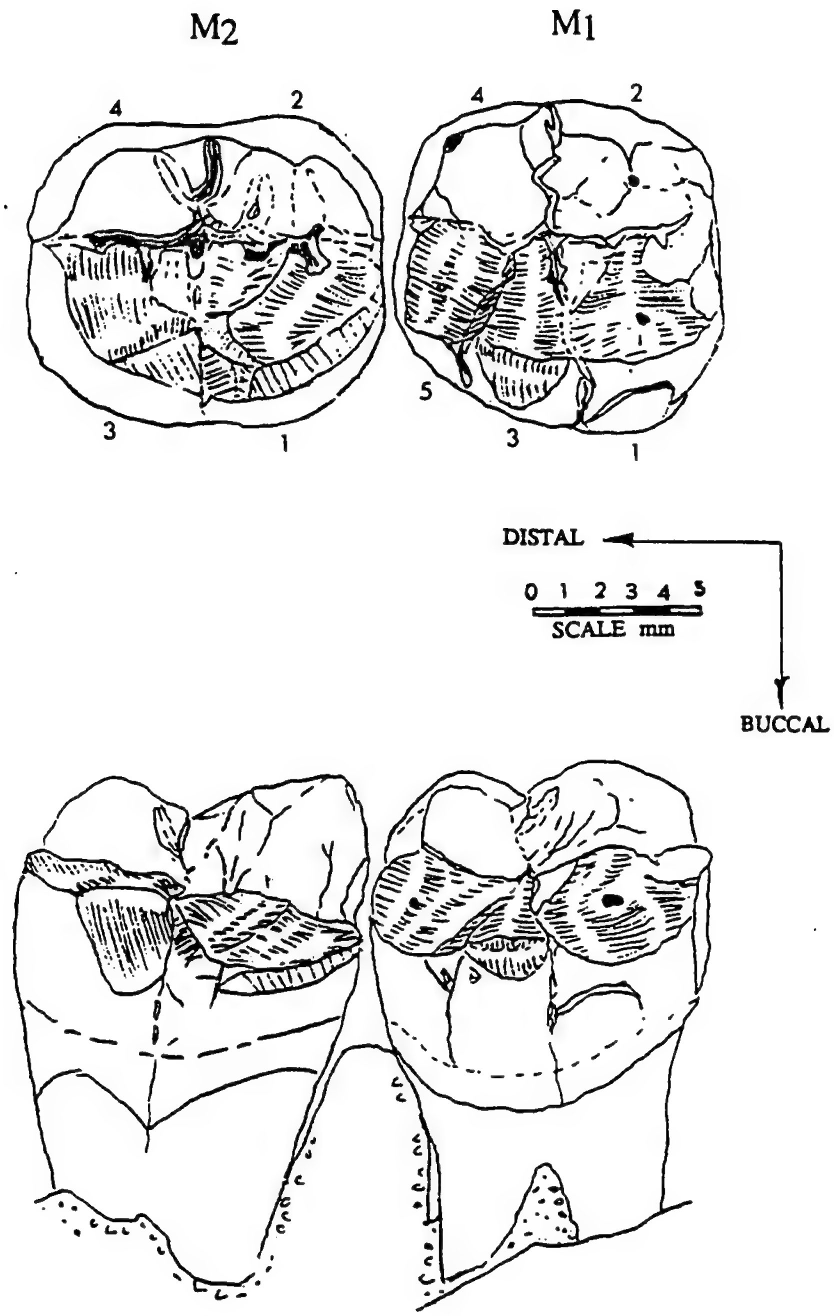


Figure 5.26. Drawing of RM_1 and RM_2 from Specimens MR3T-S36-N1/N2. Blackened Rectangles on Wear Facets Represent Position of SEM Fields.

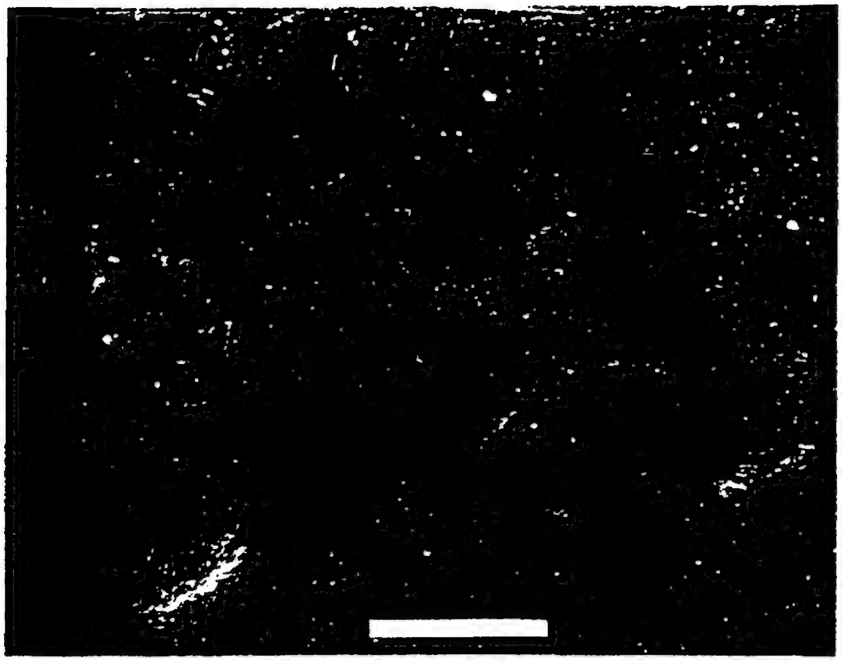


Figure 5.27. High Magnification (500x) Micrograph of Facet 1 from MR3T-S36-N1, Field 2514. Scale equals 50 microns.

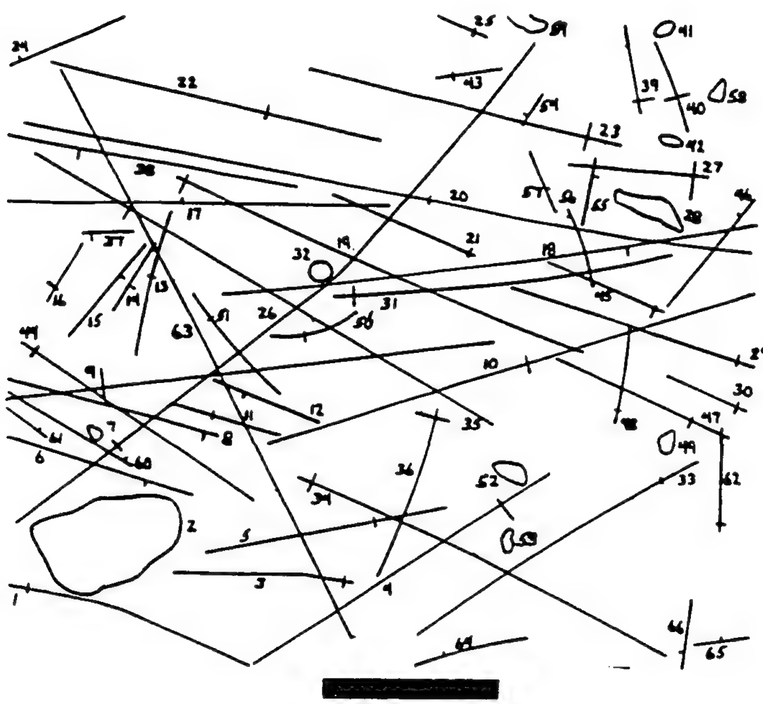


Figure 5.28. Acetate Transparency of 500x Field 2512. Scale equals 50 microns.

scratches, but may also be attributed to the slightly dirty occlusal surface. Some of the tiny white specks visible in Figure 5.27 are particles of dust, while others are small deposits of caliche.

The second right lower molar from this individual (MR3T S36 N2) exhibits a moderate degree of wear (Molnar score = 2; Scott score = 10), with a completely concave occlusal plane that is oriented in a lingual-buccal direction. The entire occlusal surface is worn, although the lingual cusps retain more of their natural height than the buccal cusps (Figure 5.26a and b). The cuspal morphology has been obliterated, with the exception of cusp 2, but all of the sulci are intact. Prominent shearing and grinding wear facets are present on the buccal cusps, including Phase I facets 1 and 2 on cusp 1, and facet 6 on cusp 3. Facet 1 is planar to slightly concave and exhbits an extremely pitted surface, when examined at low power (10-30x). Facet 2 is bifacetted, consisting of a small triangular-shaped distal portion that is planar to slightly convex, and an elongated and heavily pitted planar to convex surface located mesially.

The high magnification and moderately tilted (16 degrees) field illustrated in Figure 5.29 (2629T) is taken from facet 2 at approximately the center of the very small triangular-shaped region (Figure 5.26a). Present on the facet are numerous fine and medium-width transverse scratches, with predominantly two orientations: buccolingual scratches (lower left to upper right, respectively), and mesiodistal scratches (lower right to upper left, respectively) oriented at roughly right angles to the former. Several pits, ranging in size from small to large, are also present on the facet surface. Morphologically, most of the very fine scratches exhibit sharp and smooth margins, with smooth sides and troughs. Wider scratches exhibit predominantly rough and rounded margins, and rough sides and troughs. These features are also graphically depicted in an acetate transparency (Figure 5.30) of normal field 2627T. Note that scratch orientations and features depicted in Figure 5.30 do not correspond exactly with those in the tilted micrograph (Figure 5.29). This is

because the latter field is shifted slightly lingually (to the right) on the facet surface, and is rotated in a clockwise direction with respect to the normal field (not shown), due to repositioning of the instrument stage along the x-axis and to the increased stage tilt, respectively. Generally, the microwear pattern on this portion of facet 2, numerous fine and medium crisscrossed scratches and a moderate proportion of pits, contrasts markedly with the heavily pitted appearance on the majority of the facet (see discussion below). The microwear pattern has a moderately roughened appearance, due to many small pits (some of which may be "bubble" artifacts) overlying a mostly polished enamel fabric.

Examination of facet 1 and the mesial portion of facet 2 revealed that these wear surfaces are even more heavily pitted than when viewed at low magnification. These two rough-textured wear surfaces are heavily pitted and exhibit few scratches, although the mesial region of facet 2 may be more polished, less rough, and exhibit smaller pits and more scratches than facet 1. Two possiblities are suggested for the unusual microwear on these wear facets. Post mortem diagenesis could have eroded the enamel, but would not be expected to selectively target the occlusal surface. Since this tooth exhibits a more normal microwear pattern (scratches combined with pits) on other regions of the same facet (e.g., facet 2, described above) and on adjacent non-facet areas, it appears more likely that the heavily pitted surfaces are due to another factor, tooth-on-tooth wear, as a result of tooth-tooth contact near the end of the masticatory cycle (Teaford, personal communication 1993; Teaford and Runestad 1992). These investigators have suggested that small pits may be formed by tooth-tooth contact, because of the failure of enamel prisms along their boundaries (Maas 1991). As discussed for specimen MR3-35, the heavily pitted surface could have been exacerbated by dental fluorosis (see Chapter VII for further discussion). Nevertheless, the more normal microwear pattern described for the distal region of facet 2 (Figure 5.29, 2629T above) probably represents the result of abrasive particles contacting the occlusal surface during the shearing phase (Phase I) of the masticatory cycle.

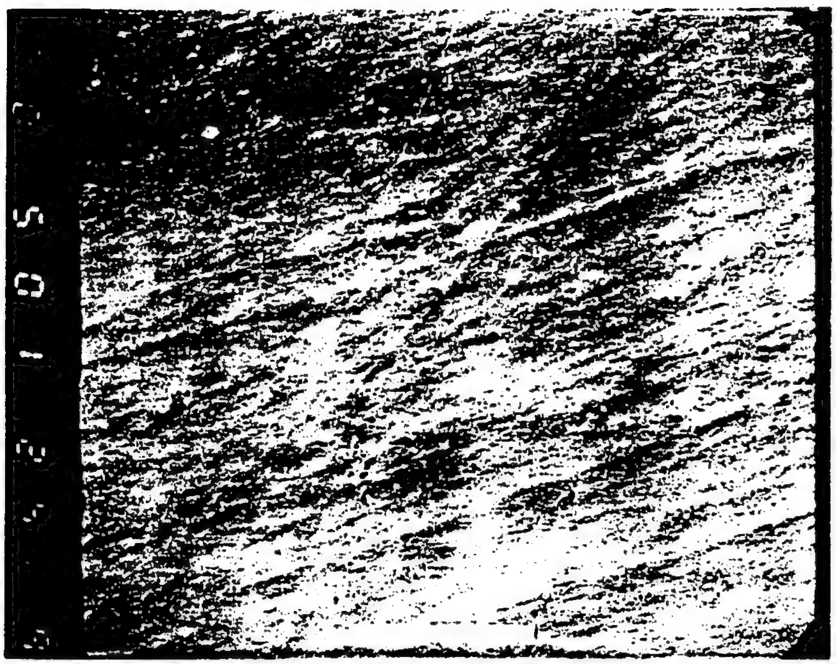


Figure 5.29. High Magnification (500x) Micrograph of Facet 2 from MR3T-S36-N2, Field 2629T. Scale equals 50 microns.

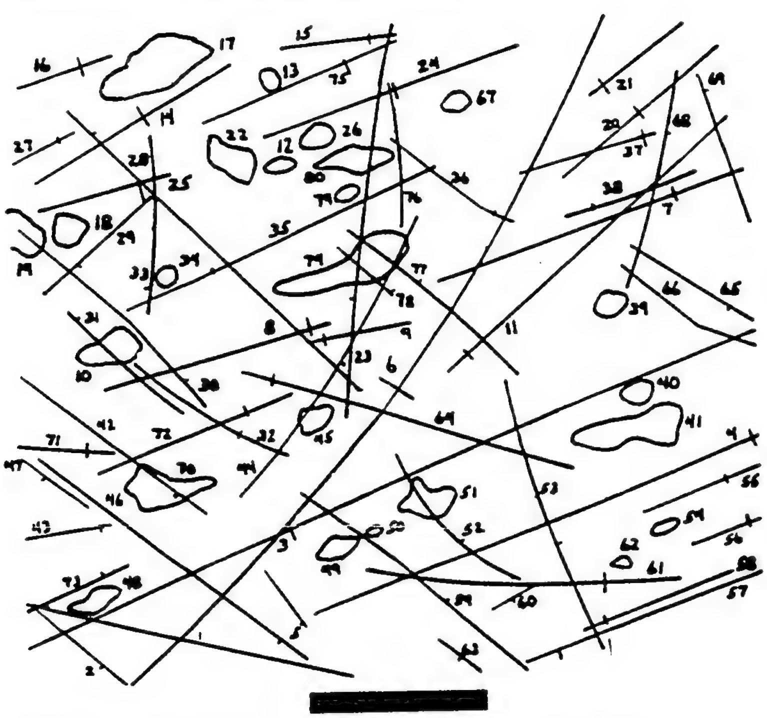


Figure 5.30. Acetate Transparency of 500x Field 2627. Scale equals 50 microns.

Inter-facet variation for dental microwear has also been recently demonstrated for extinct and extant marsupials (Robson and Young 1990; Young and Robson 1987).

Summary of Dental Attrition and Microwear

The small size of the neolithic Mehrgarh sample limits the derivation of a representative attrition and microwear pattern. Consequently, I suggest that conclusions based on comparisons with other samples be accepted cautiously. The degree of attrition for the three molars from neolithic Mehrgarh varies from slight to moderately severe. The occlusal surface form is similarly variable, with one of the lower first molars exhibiting a partially concave form, while the first and second molars from specimen MR3T-S36 exhibit a completely concave form. In all cases, the reduction in height of the crown is greatest for the buccal cusps. The form of the occlusal surface and the moderately steep oblique angle of the occlusal wear plane resemble that of other prehistoric agricultural populations (Smith 1984).

In summary, the dental microwear pattern of the three neolithic Mehrgarh molars consists primarily of numerous narrow and several medium scratches, together with several small and medium pits (Table 5.2). A very high feature density is characteristic of these molars. Inter-individual variability for scratch morphology is present: one of the first molars exhibits primarily smooth sharp margins, and smooth sides and troughs; the other first molar has scratches with predominantly rough, irregular and moderately rounded margins, and rough sides and troughs. The single lower second molar in the sample possesses narrow scratches with sharp smooth margins and smooth sides and troughs, while mostly rough and rounded margins and rough sides and troughs are present on wider scratches.

The Phase I facets of two of the neolithic Mehrgarh molars have very pitted and coarse surfaces, which are probably caused by tooth-tooth contact, or have a diagenetic

origin (see Chapter VII). However, a highly polished enamel fabric, with a more typical microwear pattern of scratches and pits, is present on portions of the facets or on inter-facet occlusal surfaces. A coarse pitted microwear pattern, consisting of compression fractures, has been reported for molar teeth from many archaeological sites in the southeastern United States (e.g., Harmon and Rose 1988; Marks et al. 1985). The compression fractures are inferred to be primarily a result of the consumption of hickory nuts (the hull was presumably ingested with the nutmeat), and various types of berries, which were consumed without removing the pit or stone. Alternatively, a coarse diet contaminated with numerous grit particles is inferred for skeletal series for whom nut shells or berry stones were not recovered (Marks et al. 1985). No botanical evidence exists for the consumption of wild or domesticated nuts by the inhabitants of neolithic Mehrgarh, but the cultivation and consumption of dates has been inferred from date stones recovered from Periods I and II (Constantini 1984; Meadow 1989). Floral remains found in neolithic levels at Mehrgarh consist of wild and domesticated varieties of barley and wheat, which were prepared using large grinding stones (Lechevallier and Quivron 1981; Meadow 1984a, 1986, 1989). It is possible that the coarse microwear pattern observed on some of the Mehrgarh molar facets is attributable to tooth-food-tooth contact involving coarse grit particles or fruit stones (date, jujube), rather than to the tooth-on-tooth contact observed in studies of extant New World monkeys (Teaford and Runestad 1992). A more detailed discussion of these and other characteristics of the neolithic Mehrgarh microwear pattern is presented in Chapter VII.

Chalcolithic Mehrgarh (MR2)

<u>MR2-34</u>

Occlusal attrition of the first mandibular molar (MR2 34 H1) of this individual, a young adult male, has resulted in an oblique (lingual to buccal) wear plane in which the

occlusal surface form is completely concave. The relatively light degree of wear scored on this specimen (Molnar score = 2; Scott score = 9) has left much of the lingual cusp morphology intact, affecting cusp 4 the least. However, the buccal cusps are rounded and possess both convex and concave occlusal wear facets. Interstitial wear facets are also present on both mesial and distal surfaces of the crown. The attrition on cusps 3 and 5 is great enough to have partially obliterated the "Y" pattern of the central sulcus, as well as the buccal groove. Cusp 1 (protoconid) exhibits a slight amount of attrition with exposure of a small dentinal pit. Also present are two large Phase I shearing facets (facets 1 and 2) on the buccal-occlusal margin and a Phase II facet near the buccal and mesial edges of the dentinal pit. Facet 1 exhibits a convex surface that is tilted cervically in a distobuccal direction. Areas of flourotic pitting and discoloration are present on this specimen (Lukacs et al. 1985; Lukacs 1985b; see Chapter III), including some small pits on the buccal surface of cusp 3, possibly a small patch or two on the distal portion of facet 1, and on the lingual surface of the tooth.

Figure 5.31 is a high magnification micrograph (1419N) taken from a strongly tilted (21.5 degrees) field on facet 1. The field of high magnification analysis is located approximately at the center (buccolingually) of the facet, but at the mesial end adjacent to facet 2 where flourotic pitting is not present. Some deep postmortem gouges in the enamel surface are located on the facet, but distal to the field of analysis. Present are many medium to wide transverse scratches and several narrow ones. The predominant orientation is buccolingual (lower left to upper right, respectively), while a few additional scratches are orientated at roughly right angles to the others and in an approximately mesiodistal direction (bottom to top, respectively). Several small to medium pits are also present. These features are illustrated in the acetate transparency of the normal field 1417N (Figure 5.32). In addition, several pits and short narrow scratches, not originally analyzed quantitatively, were later added to the unmeasured count category. It should be noted that

not all features depicted in the acetate transparency (Figure 5.32) correspond to those illustrated in the micrograph (Figure 5.31), because the two fields were displaced slightly from each other in a distolingual direction, due to relatively different stage placement.

With regard to scratch morphology, the majority of wide scratches possess moderately smooth and rounded margins, as well as moderately smooth sides and troughs. Few scratches have rough sides and troughs, or sharp angular margins. Generally, the enamel fabric of this facet appears to be polished, but cut by numerous medium to wide and several fine scratches. Many of the small oval depressions visible in the micrograph resemble enamel prism boundaries, rather than "pitting" artifacts or microwear features.

The second right molar of this individual (MR2 34 H2) exhibits slight to moderate attrition (Molnar score = 2; Scott score = 7), with a natural form still present on much of the occlusal surface. Of the lingual cusps, cusp 4 retains its natural crenulations while cusp 2 exhibits slight wear. No dentine is exposed on the occlusal surface of the more worn buccal cusps, but large concave and convex-shaped shearing and grinding facets are present. The Phase I facet used in this analysis (facet 1), adjacent mesially to the large buccal pit, exhibits a convex to slightly concave shape and is tilted strongly in a cervical and a slightly distal direction.

The high magnification micrograph illustrated in Figure 5.33 (1519T) is taken from a strongly tilted (21 degrees) field located at the upper right (mesial-apical) corner of facet 1. The majority of long fine to wide parallel scratches are oriented buccolingually (lower left to upper right, respectively), while several more nearly vertical scratches exhibit mesiodistal to mesiobuccal-distolingual orientations (bottom to top, respectively). Several small to medium pits are also present, primarily in the upper half of the micrograph. The microwear features are further illustrated in the acetate transparency taken from normal field 1517T (Figure 5.34). A considerable number (23) of additional scratches not illustrated in

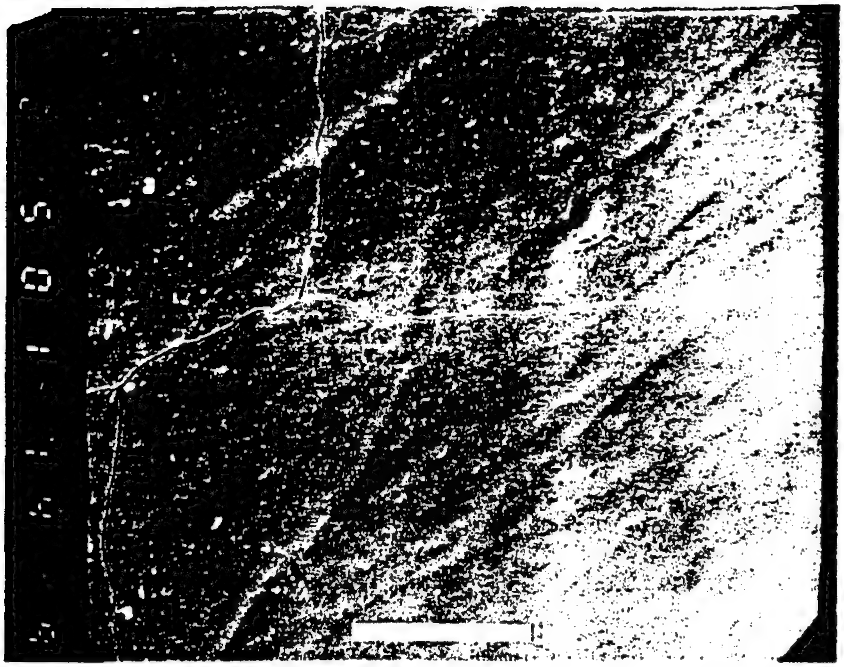


Figure 5.31. High Magnification (500x) Micrograph of Facet 1 from MR2-34-H1, Field 1419N. Scale equals 50 microns.

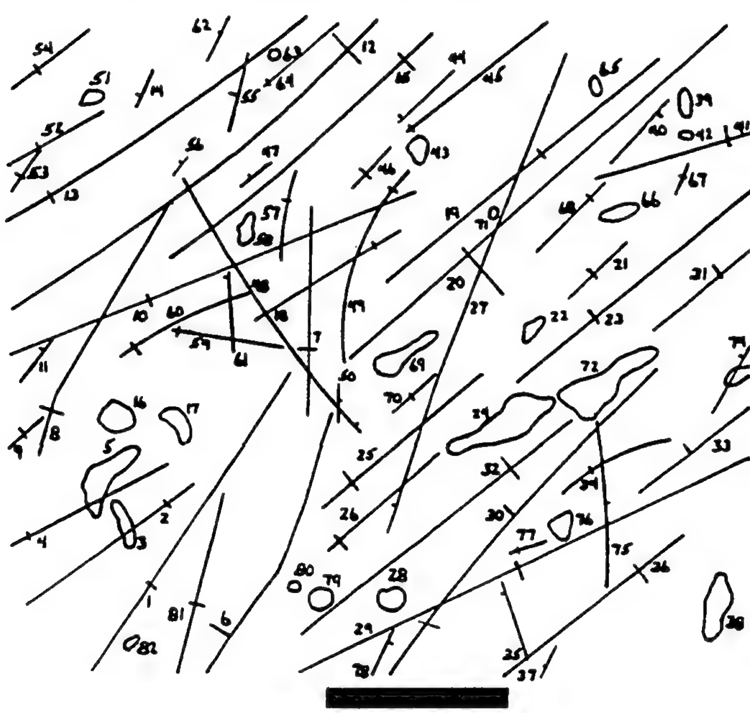


Figure 5.32. Acetate Transparency of 500x Field 1417N. Scale equals 50 microns.

Figure 5.34 are visible in the tilted micrograph field (Figure 5.33), and were recorded as part of the unmeasured count for this specimen.

The scratch morphology is somewhat variable, with moderately rough margins, sides and troughs on some scratches, but a generally smooth morphology for many scratches. While many sharp-margined scratches are present, many of the medium to wide scratches exhibit more rounded margins. Generally, the enamel fabric has a rough-textured appearance, due to the high density of scratches, many of which cross each other.

MR2-36A

The first permanent mandibular right molar (MR2 36A F) from this juvenile individual was unerupted at the time of death or had been in occlusion for only a brief period, as determined by the presence of partially-formed roots (broken) and a crown with a completely natural form. When viewed under low magnification, perikymata are quite visible on the outer surfaces of the crown, and all cusps possess sharp tips and distinctive crenulations, and lack noticeable attrition, chipping or wear facets (Molnar score = 1; Scott score = 4). The complex crown morphology includes the presence of a small fifth cusp (hypoconulid), a pronounced deflecting wrinkle on the second cusp, and a buccal pit consisting of a series of slight depressions (Turner n.d.).

The micrograph illustrated in Figure 5.35 (1111) is a high magnification image of the convex surface at the buccal-occlusal margin, in a homologous position to that of facet 1. Visible on the micrograph are several long shallow transverse furrows (oriented from upper right to lower left), which are segments of perikymata. Two elevated ridges of enamel parallel the perikymata and possess numerous small depressions (dimples), producing a honeycomb or punchboard pattern. Such a pattern is characteristic of the unworn ends of enamel prisms viewed under high magnification (Bullington 1988; Scott and Wyckoff 1949, Figure 1; Scott et al. 1949; Scott and Symons 1982). The absence of

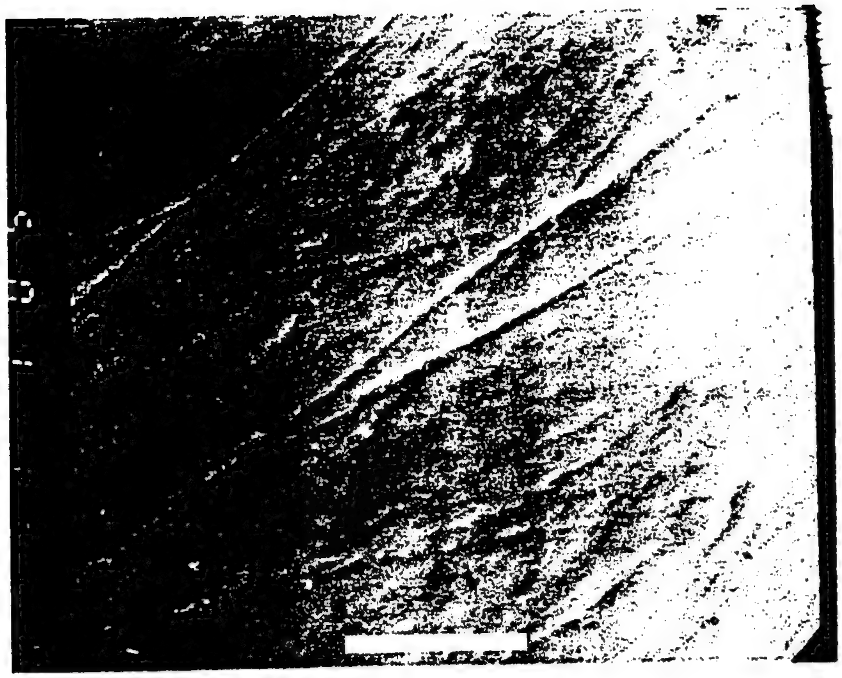


Figure 5.33. High Magnification (500x) Micrograph of Facet 1 from MR2-34-H2, Field 1519T. Scale equals 50 microns.

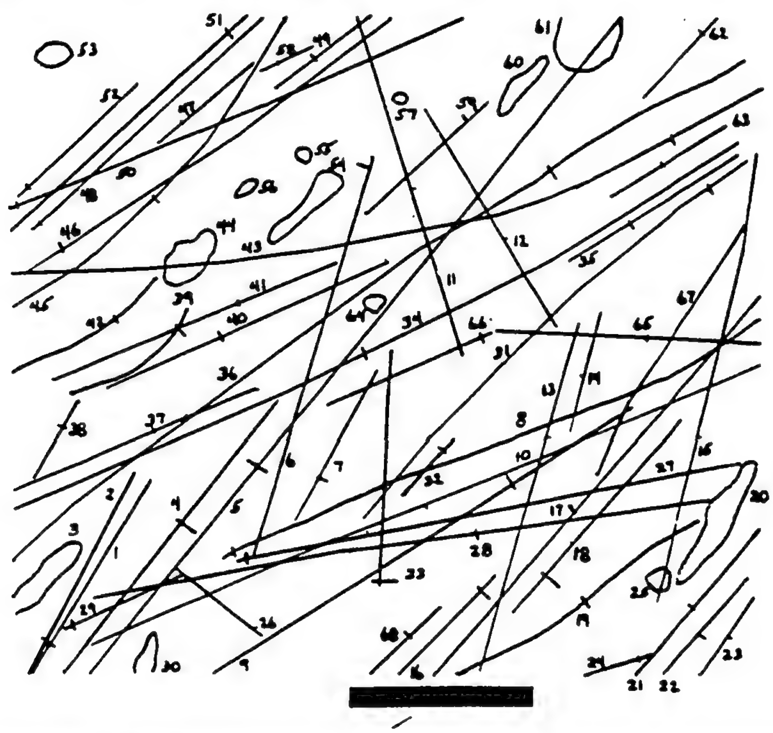


Figure 5.34. Acetate Transparency of 500x Field 1517T. Scale equals 50 microns.

The micrograph illustrated in Figure 5.35 (1111) is a high magnification image of the convex surface at the buccal-occlusal margin, in a homologous position to that of facet 1. Visible on the micrograph are several long shallow transverse furrows (oriented from upper right to lower left), which are segments of perikymata. Two elevated ridges of enamel parallel the perikymata and possess numerous small depressions (dimples), producing a honeycomb or punchboard pattern. Such a pattern is characteristic of the unworn ends of enamel prisms viewed under high magnification (Bullington 1988; Scott and Wyckoff 1949, Figure 1; Scott et al. 1949; Scott and Symons 1982). The absence of microscopic striations on the enamel surface is characteristic of very young individuals (Bullington 1988; Teaford and Walker 1983; Teaford 1988b). The sharply-defined pits on the enamel surface are probably true microwear features, and not of postmortem origin, because similar features were observed on the occlusal-buccal margins of other parts of the protoconid and on the hypoconid (cusp 1). These features are also illustrated in the acetate transparency from the micrograph (Figure 5.36). The occlusal-buccal margins of the mesial and distal sides of the tooth showed only undisturbed prism ends (punchboard appearance), together with an occasional jagged feature that may have been produced from the coalescing of the prism ends. The several small pits may have been produced by "plucking"of the enamel prisms due to adhesive wear (Walker 1980, 1984), while the larger pits were possibly caused by percussive wear from tooth-tooth contact (Teaford, personal communication 1993; Teaford and Runestad 1992). The microwear pattern of this specimen resembles the Stage I of microwear recorded by Bullington (1988) for deciduous molars.

<u>MR2-42</u>

The left first mandibular molar (MR2 42 A1) from this individual, an adult male, exhibits a severe degree of attrition (Molnar score = 4; Scott score = 21). The oblique

Figure 5.35. High Magnification (500x) Micrograph of Facet 1 from MR2-36A-F, Field 1111. Scale equals 50 microns.

Figure 5.36. Acetate Transparency of 500x Field 1111. Scale equals 50 microns.

is especially true of cusps 2, 3 and 4, although small areas of cusp 1 are also affected.

Phase I wear facets are present on all cusps, with those on cusps 1 and 3 being especially prominent. On cusp 1, facet 1 is small and has a planar to strongly convex surface, while facet 2 is a large and rectangular facet with a planar surface in a buccolingual direction, but with a concave surface in a mesiodistal direction. Under low power (10-30x) examination, these two facets and facet 6 exhibit very coarse and heavily pitted surfaces. Because a similar type of coarse surface damage extends onto much of the lingual, mesial, and distal surfaces of the crown, this unusual pattern may be a result of diagenetic processes, such as postmortem erosion of the enamel (Teaford 1988b), rather than from tooth-on-tooth contact (Teaford, personal communication 1993; Teaford and Runestad 1992) (see previous description of abnormal microwear for MR3T S36 N2; also see Chapter VII for additional discussion). However, at low magnification facet 2 exhibits such damage primarily at its center, while other unaffected regions of the facet exhibit small pits and numerous narrow scratches.

The area selected for SEM analysis was at the extreme mesiobuccal corner of the facet, several hundred micrometers lingual from the occlusobuccal margin. A high magnification micrograph (Figure 5.37, 0129N) was produced from a strongly tilted (25 degrees) field located in this region. Present are numerous fine to wide scratches, some of which are crisscrossed, as well as numerous small to large pits. In general, three scratch orientations are represented: the approximately vertical scratches are oriented in a buccolingual (bottom to top, respectively) direction; the few horizontal to slightly transverse scratches are oriented approximately mesiodistally (left to right, respectively); and the transverse scratches have a predominantly mesiobuccal-distolingual (lower left to upper right, respectively) orientation.

Many of these features are graphically depicted in an acetate transparency (Figure 5.38) of normal field 0127N. Note that scratch orientations and features depicted in Figure

5.38 do not correspond exactly with those in the tilted micrograph (Figure 5.37). This is because the latter field is shifted slightly lingually (upward) on the facet surface, and is rotated in a clockwise direction with respect to the normal field (not shown), due to the increased instrument stage tilt and possibly to the concave facet surface. The latter factors also contributed to a much brighter and dramatically foreshortened field (mesiodistally), compared to the normal field. The many additional features, primarily fine to medium scratches, present in the tilted field were not measured as part of the quantitative analysis, but were recorded in the unmeasured count category for the specimen.

Morphologically, most fine and medium scratches have moderately rounded and smooth margins, as well as generally smooth sides and troughs. Rough margins are present on a few of the medium and wide scratches. Generally, the microwear pattern present on facet 2 consists of a high density of features, predominantly numerous fine to medium scratches, some of which are crisscrossed, and numerous pits. As a result of the high feature density, the enamel fabric appears rough-textured, with only small islands of unaffected enamel remaining between the microwear features.

The degree of attrition present on the occlusal surface of the lower left second molar from this specimen (MR2 42 A2) is less severe than for the first molar, but the wear is sufficient to have affected most of the occlusal surface of the tooth (Molnar score = 2; Scott score = 10). The entire crown has been reduced in height and the buccal cusps are flattened, while the lingual cusps are rounded and retain some of their original height. The oblique occlusal wear plane is oriented in a lingual-buccal direction, and the form of the occlusal surface is partially concave. Much of the occlusal morphology has been obliterated by the wear, but the central cruciate portion of the very deep sulci and the lingual groove are intact.

Prominent Phase I wear facets are present on cusp 2, smaller ones are present on cusp 4, and very large Phase I and II facets are present on the buccal cusps. On cusp 1,

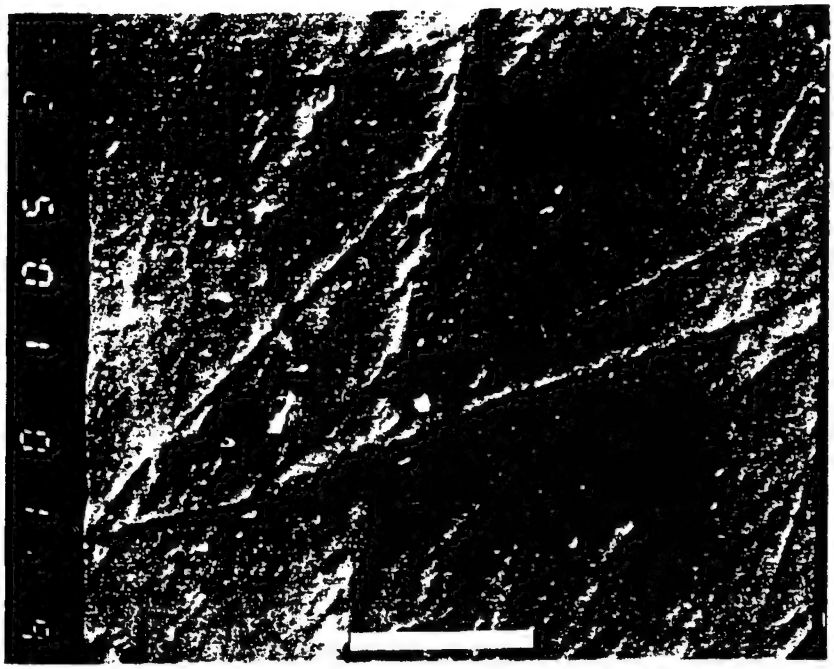


Figure 5.37. High Magnification (500x) Micrograph of Facet 2 from MR2-42-A1, Field 0129N. Scale equals 50 microns.

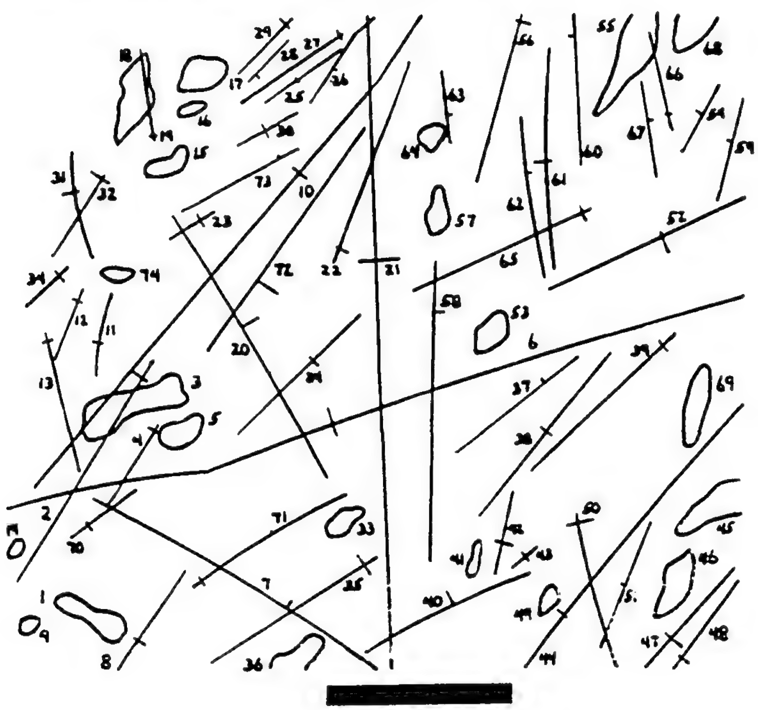


Figure 5.38. Acetate Transparency of 500x Field 0127N. Scale equals 50 microns.

facet 1 is a large rectangular shearing facet, which has a planar to very slightly concave surface oriented in a lingual-buccal direction. Facet 1 occupies approximately two-thirds of a large wear surface, which is contiguous with facet 6 on cusp 3, but separated by a narrow postmortem crack that follows the route of the worn buccal groove (not present). The surface of facet 6 is also planar and slightly concave, but the facet plane is tilted slightly mesially as well as buccally. At low magnification (10-30x), both of these facet surfaces exhibit very coarse and deep gouges at the buccal edge, with a similar type of coarse surface damage extending onto the entire buccal surface of the crown. As with the first molar, this unusual pattern may be due to postmortem erosion of the enamel. However, at low magnification many small pits and numerous narrow scratches are visible on regions of the facets that are unaffected by the coarse surface damage. Also present along the occlusobuccal margin at the mesiobuccal corner of the crown, facet 2 exhibits a strongly convex surface with a plane that tilts both mesially and buccally. This region of the occlusal surface does not exhibit the surface damage observed in the other two facets.

Illustrated in Figure 5.39 is a micrograph (0229T) produced from a strongly tilted (25 degrees) field on facet 2, located at approximately the center (buccolingually) of the facet and near the mesial end. Present are many narrow and medium transverse scratches, which are orientated in a predominantly buccolingual direction (lower left to upper right, respectively). A few very faint and nearly vertical scratches, with more mesiolingual-distobuccal orientations (top to bottom, respectively), are also present. The few wide horizontal scratches exhibit mesiobuccal-distolingual orientations (left to right, respectively). Several small and medium pits are also present, especially in the lower half of the field. Many of these features are also illustrated in an acetate transparency taken from normal field 0227T (Figure 5.40). A large number of additional fine and medium scratches present in the tilted field (0229T, Figure 5.39), but not represented in Figure 5.40, are a result of the better contrast, brightness and slight foreshortening (left to right) of

field 0229T. Some postmortem defects in the replica consist of a long crack at the center of the field, and two small patches at the upper right where the gold coating has sluffed off (Figure 5.39).

Generally, the enamel fabric of this facet exhibits a polished appearance, with an overlying microwear pattern consisting of a high density of crisscrossed scratches. Scratch morphology is somewhat variable, consisting of many scratches with smooth sharp margins, and moderately smooth sides and troughs. Additionally, moderately rough but rounded margins, rough sides and troughs are present on other scratches.

<u>MR2-45</u>

The left lower first molar (MR2 45 I1) from this individual exhibits a severe degree of attrition (Molnar score = 3; Scott score = 18), which has produced a completely concave and oblique wear plane that is oriented in a lingual-buccal direction (Molnar 1971a). Wear is present on the entire occlusal surface, although the height and morphology of the lingual cusps are much less reduced than that of the buccal cusps, which are completely flattened. A large lake of exposed dentine is present on cusp 1 (Figures 5.41, 5.42) as well as cusp 3. The lingual groove and portions of the central sulcus remain intact, but the buccal groove has been almost completely obliterated by the severe wear. Prominent Phase I wear facets (facets 1 and 6) are present at the occlusobuccal margin of cusps 1 and 3, respectively. However, examination at low magnification (15-30x) with an optical microscope revealed a very grainy or pebbly texture to the facet surfaces (Figure 5.42). High power examination with the SEM revealed that these wear surfaces are even more heavily pitted and gouged than when viewed at low magnification. However, a more normal microwear pattern (scratches combined with pits) is present on other non-facet occlusal surfaces, such as the occlusobuccal margin at the mesiobuccal corner of cusp 1. As with the neolithic Mehrgarh specimen MR3T S36 N2, the abnormal wear surfaces of

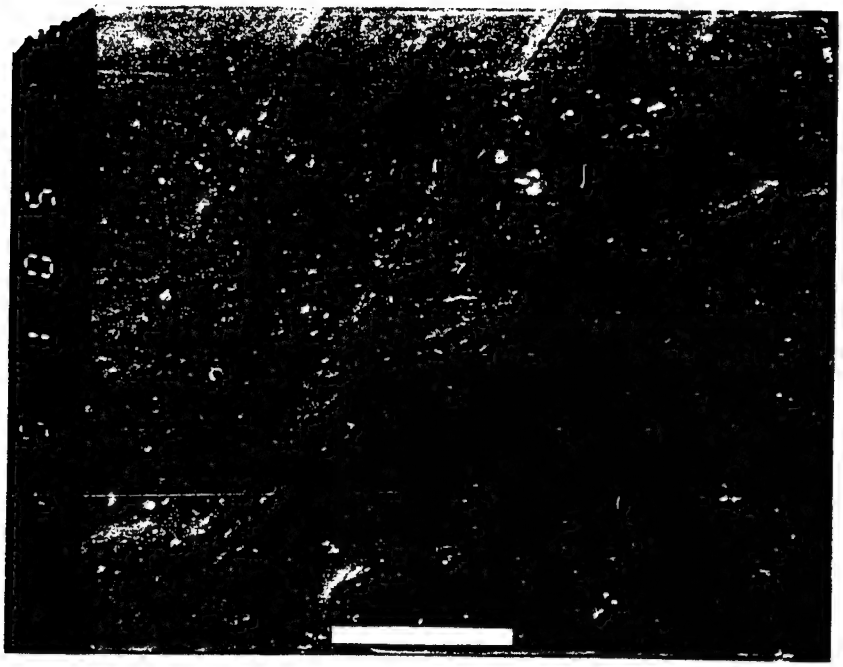


Figure 5.39. High Magnification (500x) Micrograph of Facet 2 from MR2-42-A2, Field 0229T. Scale equals 50 microns.

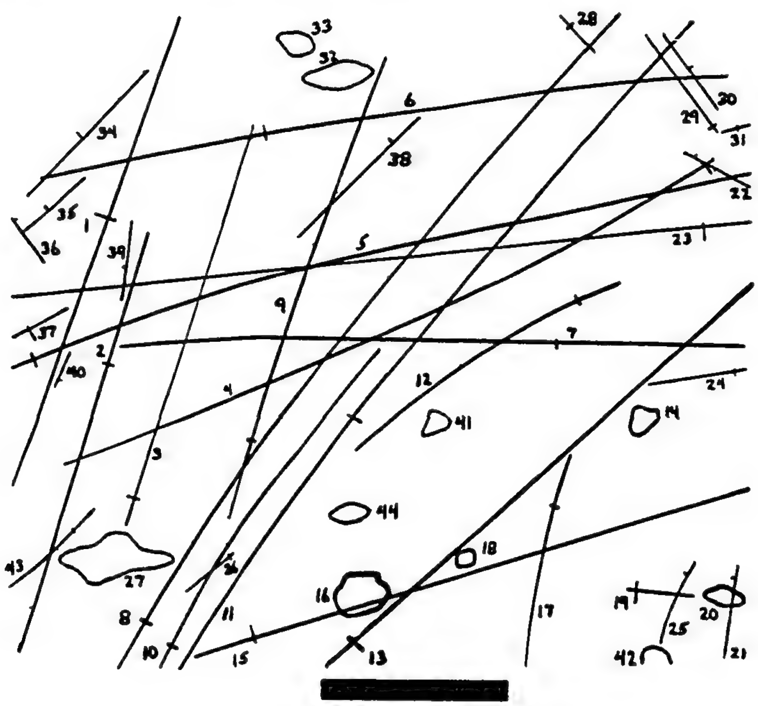


Figure 5.40. Acetate Transparency of 500x Field 0227T. Scale equals 50 microns.

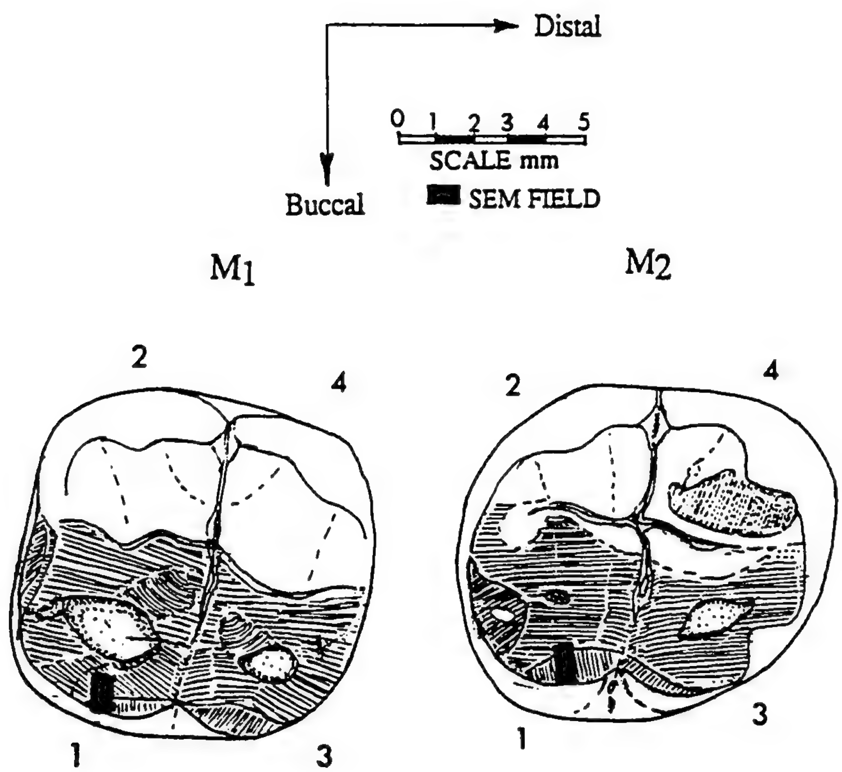


Figure 5.41. Drawing of RM_1 and RM_2 from Specimens MR2-45-I1/12.
Blackened Rectangles on Wear Facets Represent Position of SEM Fields.

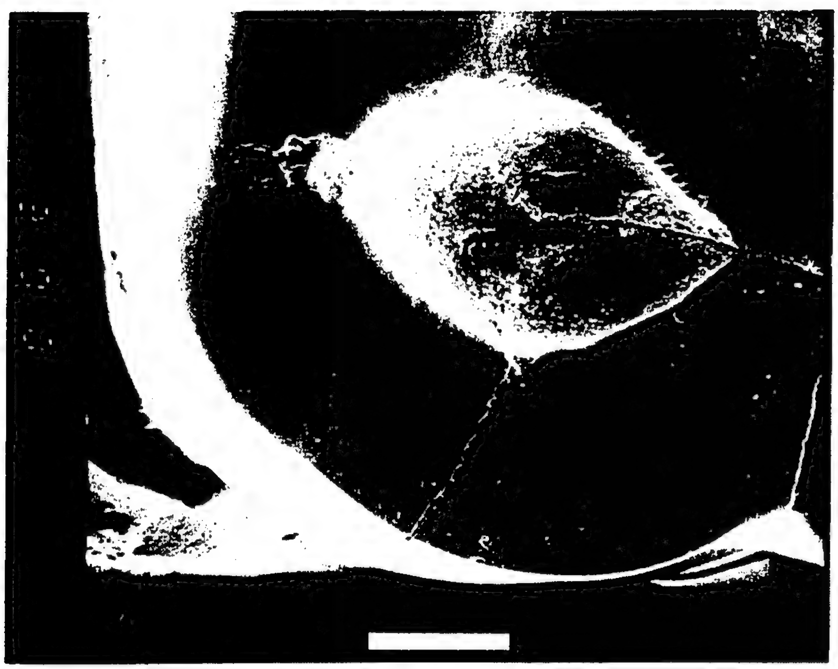


Figure 5.42. Low Magnification (20x) Micrograph of Cusp 1 from MR2-45-I1, Field 1602. Scale equals 1000 microns.

facets 1 and 6 may be attributed to tooth-on-tooth wear, as a result of tooth-tooth contact near the end of the masticatory cycle (Teaford, personal communication 1993; Teaford and Runestad 1992) (see previous description of abnormal microwear for MR3T S36 N2).

The area selected for high magnification analysis is located on a convex to strongly convex platform of enamel at the occlusobuccal margin, mesial to facet 1, and in a homologous position to facet 2 (Figure 5.42). Figure 5.43 illustrates a high magnification micrograph (1629T) taken from a strongly tilted (25 degrees) field, located adjacent to the mesial edge of facet 1 and lingual to the occlusobuccal margin. Visible in the micrograph are numerous vertical to slightly transverse scratches, of medium to wide width, that are oriented approximately buccolingually (bottom to top, respectively), as well as several small and large pits. Also present are several strongly transverse scratches oriented in a more mesiobuccal-distolingual direction (lower left to upper right, respectively). The latter vary in width from narrow to wide, with most of the narrow scratches (e.g. at upper left and lower right) visible only in the tilted field (Figure 5.43). As a result, the features illustrated in the acetate transparency produced from the normal field 1627T (Figure 5.44) are only a partial inventory. This situation is also partially due to slight foreshortening of the tilted field in a distomesial direction (lower right to upper left, respectively). Although these additional features were not included in the metric analysis, the total was added to the unmeasured count category for this specimen. The dark crescent-shaped feature at left of center (Figure 43) is an artifact caused by loss of the gold coating as a result of damage to the coated replica during transit between laboratories. Several white specks above this feature are particles of dust.

Morphologically, the scratches present on this facet exhibit sharp but rough margins, and the troughs are mostly rough, especially for the medium to wide scratches. Some of the fine scratches exhibit rounded margins and smooth troughs. While the enamel fabric appears smooth and polished, the numerous scratches, some of which are

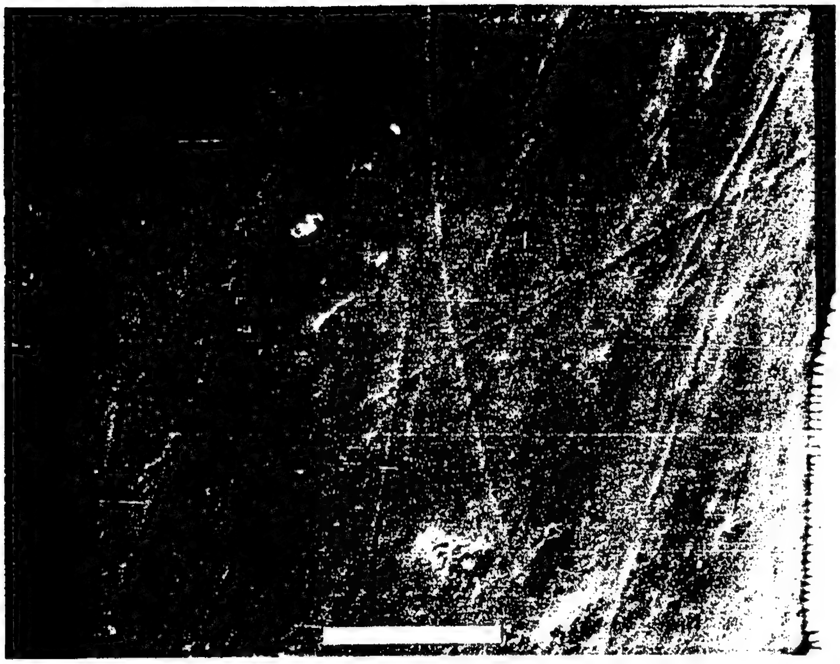


Figure 5.43. High Magnification (500x) Micrograph of Facet 2 from MR2-45-I1, Field 1629T. Scale equals 50 microns.

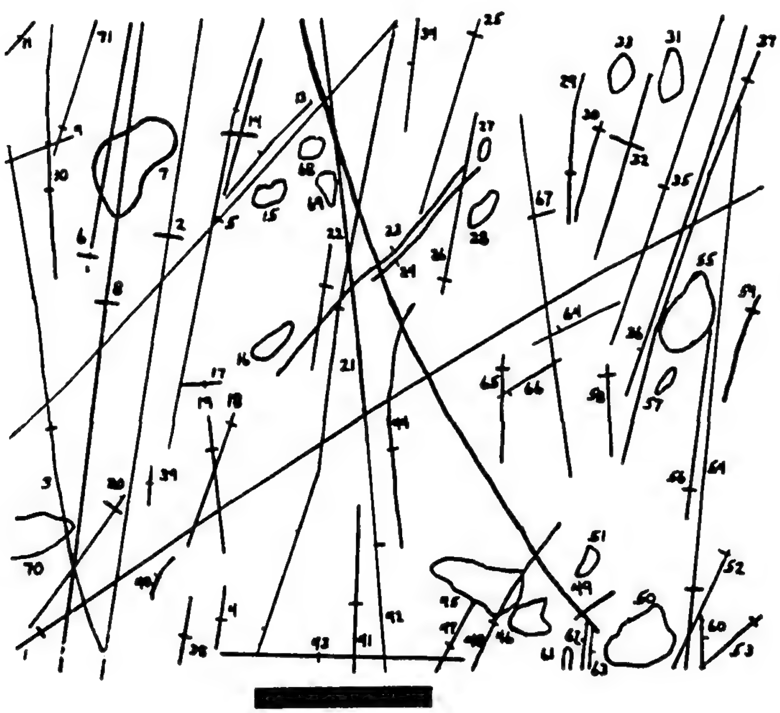


Figure 5.44. Acetate Transparency of 500x Field 1627T. Scale equals 50 microns.

crisscrossed, produce an overlying rough texture to the wear surface.

The moderate occlusal attrition (Molnar score = 3; Scott score = 12) of the second left lower molar (MR2 45 I2) from this individual has resulted in flattening of the buccal cusps, but only partial reduction in height of the lingual cusps. As a result, a small dentinal pit is exposed on cusp 1 and a larger patch of exposed dentine is present on cusp 3 (Figures 5.41, 5.45). The oblique wear plane is oriented in a lingual-buccal direction and the occlusal surface form is partially concave. Much of the natural occlusal morphology has been obliterated by the wear, including the buccal groove and distal portion of the central sulcus. Cuspal crenulations are present on cusp 2, while the other three cusps exhibit Phase I and II wear facets. The prominent Phase I facets present on cusp 1 (facets 1 and 2) exhibit pebbly and grainy surfaces when examined at low and high magnification, similar to that observed for the first molar (Figure 5.45, cf. previous discussion for specimen I1). However, non-facet convex enamel surfaces exhibit a more normal microwear pattern, consisting of polished enamel with scratches and pits. Such surfaces are present along the occlusobuccal margin of cusp 1 between the Phase I facets and on a distinct and slightly-bevelled platform of enamel along the occlusobuccal margin of cusp 3 (hypoconid). The latter is convex to strongly convex in shape and homologous to facet 6.

Although high magnification micrographs were produced from these non-facet surfaces on both cusps 1 and 3, the micrograph from "facet " 6 was selected for analysis because of the slightly higher density (judged subjectively) of features than on micrographs from "facet" 2 on the protoconid. The micrograph illustrated in Figure 5.46 (1769T) is taken from a strongly tilted (25 degrees) field located directly adjacent to the buccal groove and pit, and near the lingual margin of the convex enamel surface. Feature density is very high, consisting primarily of numerous narrow to wide transverse scratches oriented in a predominantly buccolingual direction (lower left to upper right, respectively). Several vertical scratches, also of variable width, are oriented in a more mesiolingual-distobuccal

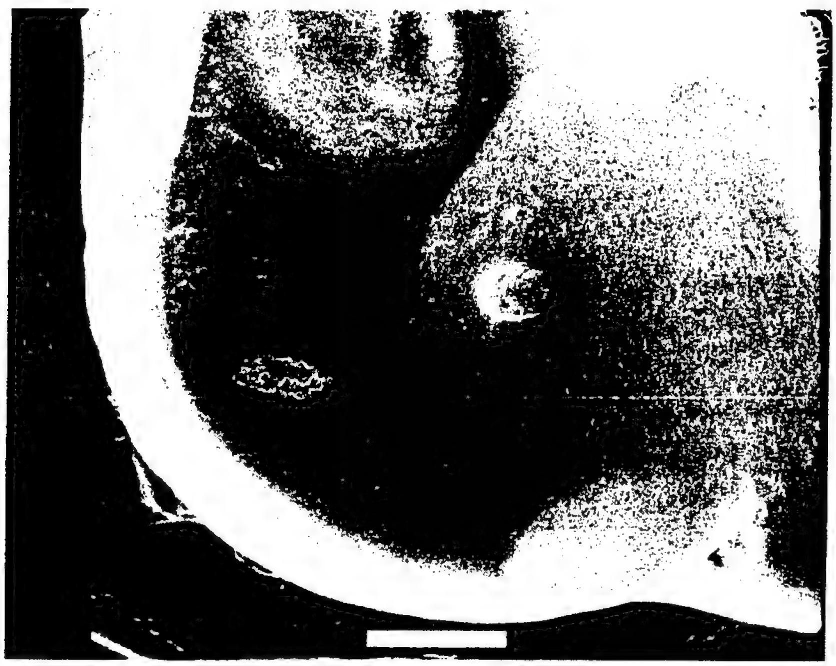


Figure 5.45. Low Magnification (20x) Micrograph of Cusp 1 from MR2-45-I2, Field 1701. Scale equals 1000 microns.

direction (top to bottom, respectively), and several small and large pits are also present. Most of these features are illustrated in the acetate transparency from the micrograph taken from the normal field (Figure 5.47, 1767T). Many additional scratches were recorded under the unmeasured count category for field 1769T, because of dramatic foreshortening relative to field 1767T, which effectively increased the surface area of enamel visible at the right and left margins of the field. This foreshortening was produced as a combination of the strongly tilted instrument stage and the strongly convex enamel surface.

Scratch morphology consists predominantly of rounded and rough margins, with rough sides and troughs. Some of the fine scratches exhibit smooth and sharp margins, with smooth sides and troughs. The texture of the enamel fabric is reminiscent of the Mahadaha specimens, where an elephant skin appearance is created by many short crisscrossed scratches.

MR2-46

The moderate degree of attrition (Molnar score = 3; Scott score = 15) exhibited by the lower right first molar of this specimen (MR2 46 J1) has produced a dramatic reduction in height of cusps 1, 3 and 5, while the lingual cusps are minimally worn. Cusp 4 retains much of its original morphology, but the tip and lingual face of cusp 2 have been shattered postmortem, resulting in the loss of these parts of the crown. The oblique occlusal wear plane is oriented in a lingual-buccal direction and the occlusal surface form is partially concave. A small patch of dentine is exposed on the worn surfaces of cusps 1, 3 and 5. Much of the occlusal morphology, including the mesial portion of the central sulcus and the buccal groove, has been obliterated by the wear on these cusps. Very distinct Phase I wear facets are present on cusps 1 and 3: facets 1 and 6 are separated by a prominent buccal pit and exhibit slightly convex and strongly concave surfaces, respectively; facet 2 exhibits a strongly convex surface that transitions into a narrow bevelled platform of enamel at the

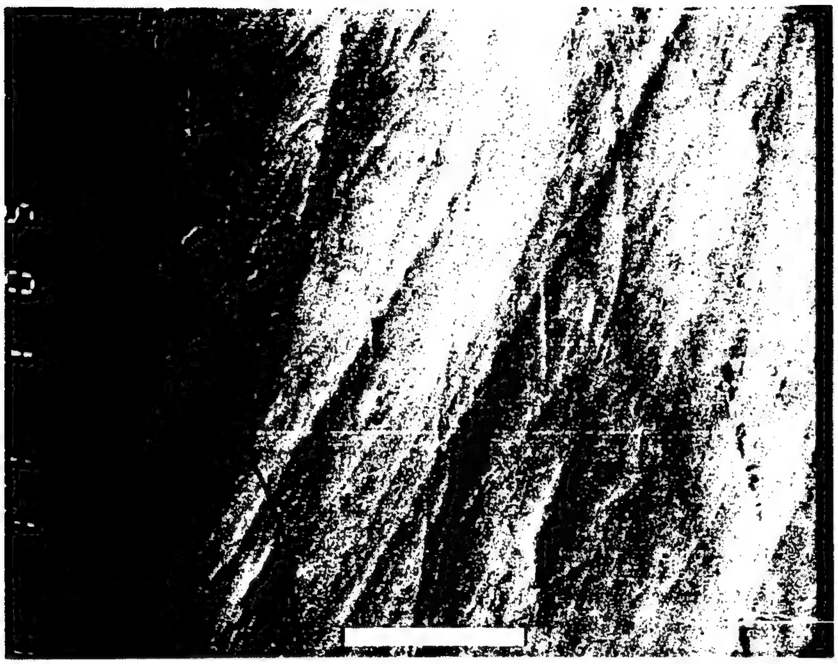


Figure 5.46. High Magnification (500x) Micrograph of Facet 6 from MR2-45-I2, Field 1769T. Scale equals 50 microns.

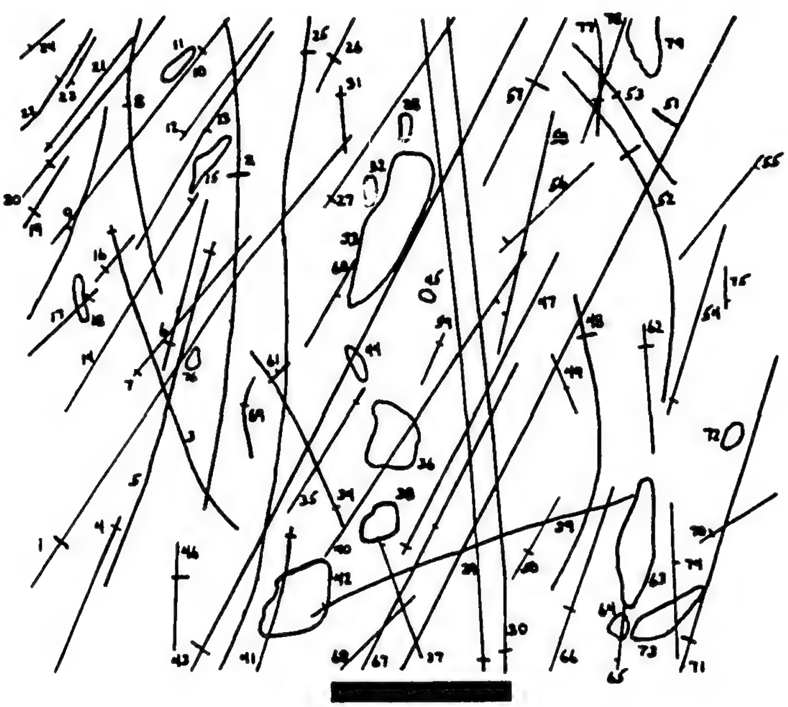


Figure 5.47. Acetate Transparency of 500x Field 1767T. Scale equals 50 microns.

mesiobuccal corner of the crown. Examination at high magnification revealed that extensive delamination (postmortem) of the original gold coat had occurred on the surface of facet 1 on the replica, obscuring the microwear features. However, this situation is less extensive on facet 2 and minimal for facet 6. Facet 2 was selected for microwear analysis because of the integrity of the gold coating, and because the density of microwear features is much higher (judged subjectively) than on facet 6.

These features are illustrated in a high magnification micrograph (Figure 5.48, 1829T) taken from a strongly tilted field (24 degrees) located near the mesial edge and adjacent to the apical (i.e. lingual) margin of the facet. Present are many medium to wide scratches orientated in predominantly two directions: mesiobuccal-distolingual (lower left to upper right, respectively); and mesiodistal (bottom to top, respectively). A smaller number of narrow scratches, with the above orientations, as well as as several small and medium pits are also present. These features are graphically illustrated in the acetate transparency produced from normal field 1827T (Figure 5.49). The dark spots and pit-like features visible at the bottom and lower left of the micrograph (Figure 5.48), and the elongated feature at the upper left were not analyzed, because of the probability that they are artifacts caused by sluffing of the gold coating on the replica. Such damage may have occurred during transit of the replica between laboratories or during preparation, although there is no indication that the facet surface had been gouged or abraded postmortem. Several additional medium-width scratches are visible in Figure 5.48, especially at the upper left, but are not present in the micrograph from the normal field (1827T, not shown). This is a result of several factors: the greater contrast and brightness of the tilted micrograph, which enhances the visibility of the features; and the sharp tilt of the instrument stage and the strongly convex facet surface, which combine to produce dramatic foreshortening of the field on the left (buccally), where the field of view has been increased by almost 20µm. These additional features were not analyzed or recorded on the acetate transparency (Figure

Figure 5.48. High Magnification (500x) Micrograph of Facet 2 from MR2-46-J1, Field 1829T. Scale equals 50 microns.

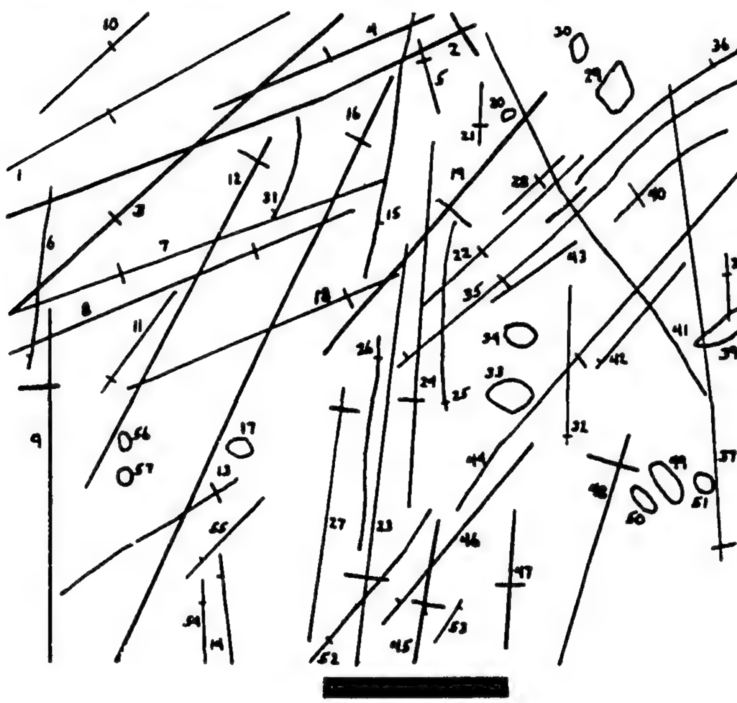


Figure 5.49. Acetate Transparency of 500x Field 1827T. Scale equals 50 microns.

5.49), but were recorded under the unmeasured count category for this specimen.

Morphologically, most scratches exhibit relatively rough margins as well as rough troughs and sides. Margin morphology is variable, with some scratches exhibiting sharp margins, while the margins of other scratches are rounded. Some of the finer scratches exhibit a generally smoother morphology. Generally, the microwear pattern consists of a high scratch density, but the frequency of pitting is lighter than on other first molar facets from chalcolithic levels at Mehrgarh. The enamel fabric is generally smooth and polished.

The lower right second molar (MR2 46 J2) exhibits a very slight degree of attrition (Molnar score = 2; Scott score = 6), and features of occlusal morphology, such as the very deep sulci and cuspal crenulations, remain intact. The occlusal plane exhibits a natural form and direction. As a result of the wear, cusps 1 and 3 are reduced very slightly in height and possess distinct Phase I and II wear facets. Facet 1 is a dual component surface with the distal side elongated and planar and showing postmortem damage (large pits and two cracks). The mesial side of this facet is slightly convex mesiodistally and exhibits no postmortem damage. The very large ovoid-shaped facet 2 presents a large slightly concave surface at the center, while the buccal and distal margins are slightly convex. An additional Phase I facet (facet 4) on cusp 1 is located cervical to the occlusobuccal margin, and adjacent to the mesial border of the large and deep buccal pit. Facet 6 is also present on cusp 3.

The high magnification micrograph (1919T) illustrated in Figure 5.50 was taken from a strongly tilted field (25 degrees) located on the mesial side of facet 1 at the mesiobuccal corner of the facet. The majority of scratches exhibit fine widths, but many medium-width scratches are also present. A single wide and coarse transverse scratch is also present at the lower left. The predominant orientations of the scratches are buccolingual (approximately left to right, respectively), and mesiobuccal-distolingual (lower left to upper right, respectively). Several oppositely transverse scratches are

oriented in a roughly mesiolingual-distobuccal direction (lower right to upper left, respectively), while a few scratches have mesiodistal orientations (bottom to top, respectively). Also present are several small and medium pits and one very large pit, especially in the upper portion of the micrographic field. A graphical depiction of these features is illustrated in Figure 5.51, an acetate transparency produced from the normal field (1917T). The positions and orientations of the features shown do not correspond exactly to those in Figure 5.50, because the tilted field is slightly rotated counterclockwise relative to the normal field (1917T, not shown), as a result of the convexity of the facet 1 surface and from the strongly tilted instrument stage.

Scratch morphology is moderately variable relative to scratch width. Most very fine scratches exhibit moderately smooth and sharp margins, with smooth sides and troughs. Many of the wider scratches have moderately rough morphology, but with more rounded margins. As with specimen MR2-34-H2, this morphological variability and the fewer crisscrossed scratches contrast with the other MR2 second molars. In general, the feature density is very high, and the overall microwear pattern is one of a low pit frequency combined with numerous scratches superimposed on an otherwise polished enamel surface.

<u>MR2-60</u>

The lower right first molar (MR2 60 C1) from this older child exhibits only slight to moderate attrition (Molnar score = 3; Scott score = 12), but this represents a relatively high rate of wear for a tooth that has been in functional occlusion for only five or six years (Scott and Symons 1982). The oblique occlusal wear plane is oriented in a lingual-buccal direction and the occlusal surface is partially concave. Cusps 1, 3 and 5 have been flattened by wear, and the lingual cusp height slightly reduced. Much of the occlusal

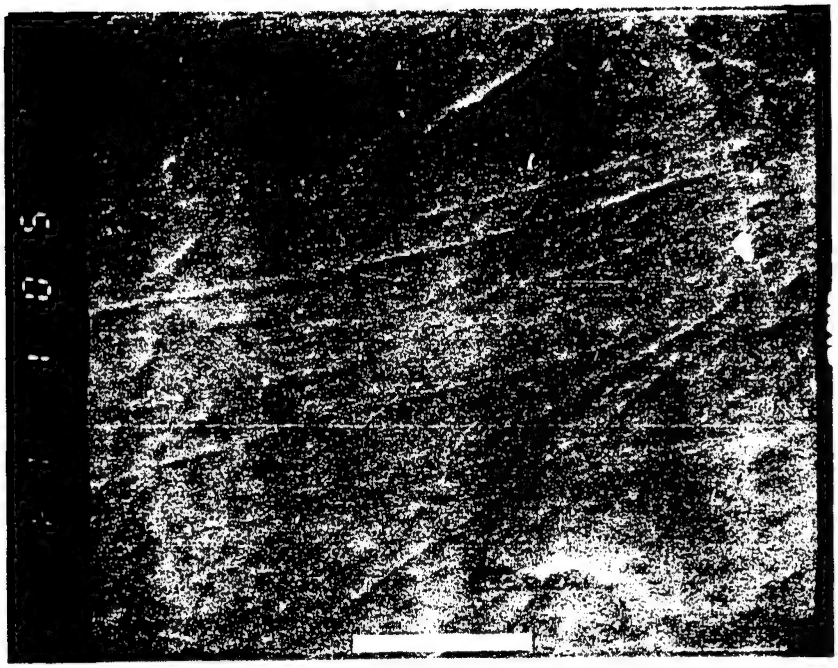


Figure 5.50. High Magnification (500x) Micrograph of Facet 1 from MR2-46-J2, Field 1919T. Scale equals 50 microns.

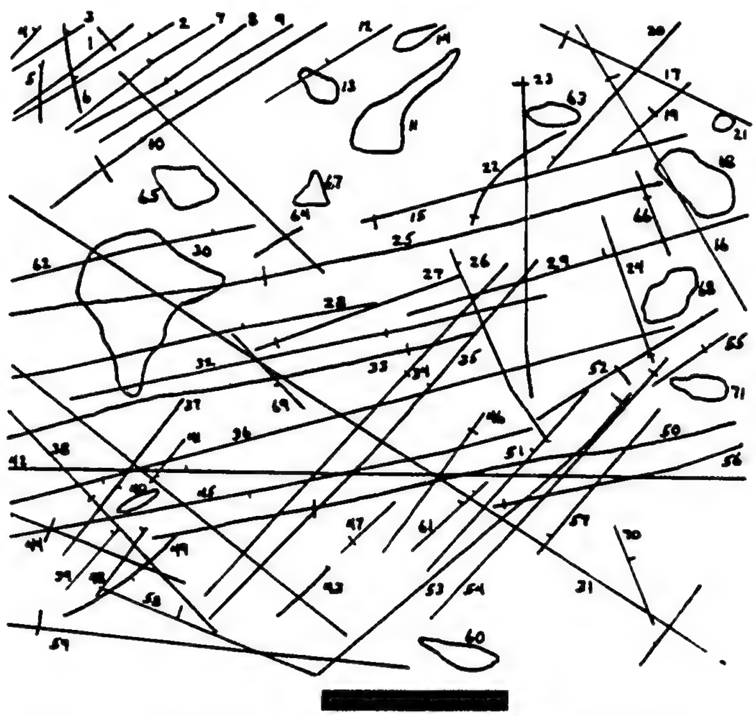


Figure 5.51. Acetate Transparency of 500x Field 1917T. Scale equals 50 microns.

morphology has been obliterated, although the sulci remain partially intact. A small patch of dentine is exposed on cusp 1, while a pinprick of exposed dentine is present on cusp 3. Small but distinct Phase I wear facets are present along the occlusobuccal margin of the buccal cusps. Facet 1 on cusp 1 is banana-shaped with a predominantly planar surface, but convex at the buccal margin. Facet 2, located at the mesiobuccal corner of cusp 1, has a very narrow ovoid shape with a planar surface buccolingually and a slightly concave shape mesiodistally. Located on cusp 3 immediately adjacent to the prominent buccal pit is facet 3, which has a planar to slightly concave surface. The entire occlusal surface has the appearance of normal worn and unworn enamel when viewed at low magnification (i.e. polished enamel with normal microwear features), unlike specimen MR2 45 I1.

Illustrated in Figure 5.52 is a high magnification micrograph (0519T) taken from a strongly tilted field (25 degrees), located slightly buccal from the center and in the distal third of facet 1. The numerous fine to wide scratches present are oriented in an approximately distobuccal-mesiolingual direction (lower left to upper right, respectively). Fewer fine to wide vertical scratches have a buccolingual orientation (bottom to top, respectively). Also present are several medium and large pits, some of which are deep and sharp-edged. Many of the features are also illustrated in an acetate transparency (Figure 5.53) taken from the normal field (0517T). Because of the dramatic foreshortening in the tilted field, many additional scratches of both orientations are only present in Figure 5.52. This is due to the expansion of field 0519T to the left (distobuccally) and possibly onto the convex buccal margin of facet 1. Consequently, the effective field area projected onto the facet was larger, and the number of features visible greater than on the normal field. The many parallel scratches located on the odd platform at the upper right (Figure 5.52) were not analyzed, because they may be brush marks from preparation activities or result from diagenesis or other postmortem damage (Teaford 1988b).

As with specimen MR2 46 J1, more variability is present for scratch morphology,

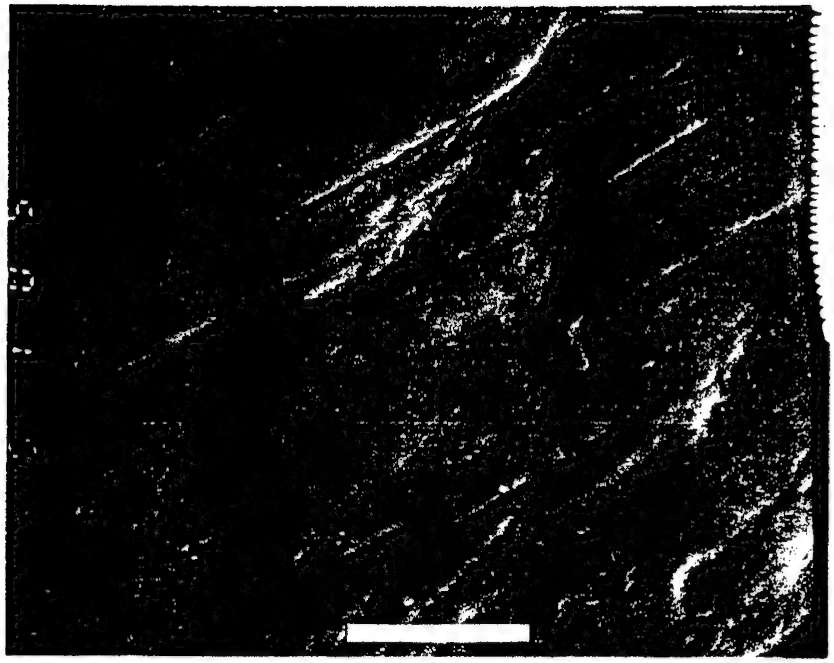


Figure 5.52. High Magnification (500x) Micrograph of Facet 1 from MR2-60-C1, Field 0519T. Scale equals 50 microns.

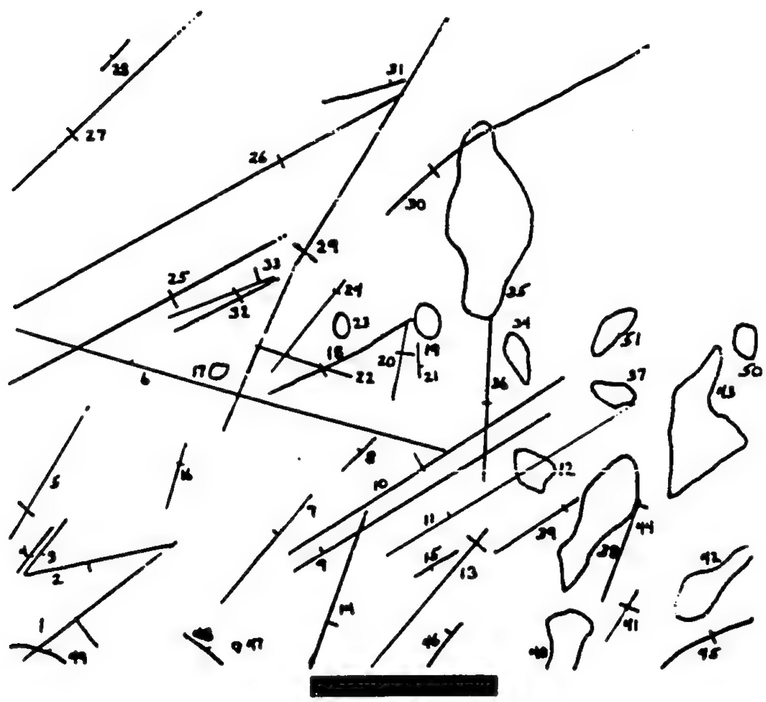


Figure 5.53. Acetate Transparency of 500x Field 0517T. Scale equals 50 microns.

especially for margin morphology, than with the other MR2 first molars. Generally, the margins of most scratches are sharp and angular, but fine scratches also have smooth margins as well as smooth sides and troughs. Relatively rough margins, sides and troughs are present on most medium and wide scratches. This specimen is also unusual for the larger pit size, compared to the other specimens. Generally, the enamel fabric appears to be a polished surface, which has been roughened by a microwear pattern consisting of numerous crisscrossed scratches, and medium and large pits.

The lower right second molar (MR2 60 C2) is very slightly worn (Molnar score = 3; Scott score = 8), which has affected the distal half of the occlusal surface differently from the mesial half. Although the occlusal plane is generally orientated in a lingual-buccal direction, differential wear of the distal cusps has produced a completely concave occlusal surface, while one-half of the occlusal surface is cupped on the mesial half of the crown (Molnar 1971a). The wear is most severe on cusp 1, which is flattened and has a pinprick of exposed dentine as well as Phase I and II wear facets. The less severe wear on cusps 3 and 4, has produced partial flattening as well as Phase I and II facets, but no dentine exposure. The occlusal morphology of cusp 2 is intact. Much of the occlusal morphology, including sulci, remains intact. Facet 1 is located adjacent to the mesial border of a very large and deep buccal pit. It is a very small triangular-shaped facet that leads mesially into a narrow strongly convex surface. The entire facet is strongly convex, but slightly flat apically (lingually). Located at the mesiobuccal corner of cusp 1, the large triangular facet 2 exhibits a mildly to strongly convex surface. Facet 6, present on cusp 3, is a large rectangular facet with a planar surface.

Illustrated in Figure 5.54, is a high magnification micrograph (0619N) produced from a strongly tilted field (25 degrees), located on the mesial end of facet 1 where the facet surface transitions into a narrow convex band of worn enamel. A very densely packed microwear pattern is present, consisting predominantly of numerous fine to wide scratches

with a more or less buccolingual orientation (bottom to top, respectively). Several much more transverse and fine to medium scratches, visible at the center and upper left, are oriented distobuccal-mesiolingually (lower left to upper right, respectively). Also present are a few fine scratches oriented at right angles to these (mesiobuccal-distolingual; lower right to upper left, respectively). These scratches, as well as many small to large pits, are illustrated in an acetate transparency produced from a normal field (0617N, Figure 5.55). Additional features not illustrated in Figure 5.55, but recorded under the unmeasured count category, are visible in the tilted micrographic field (Figure 5.54). This situation is due to greater brightness and better contrast in the latter, and to the combination of the strong degree of instrument stage tilt and the convex surface of facet 1. The latter factors have resulted in transverse foreshortening of the tilted field, revealing additional features at the lower right and upper left corners of the micrograph (Figure 5.54).

The very high feature density, consisting of numerous parallel and crisscrossed scratches together with many pits, has produced a rough-textured enamel fabric. Most scratches have rough sides and troughs. Scratch margins are generally sharp, but some are smooth or rough. This variability in margin morphology does not appear to be associated with scratch width.

Summary of Dental Attrition and Microwear

The attrition observed on the occlusal surfaces of molars from chalcolithic Mehrgarh is generally moderate, with the buccal cusps of most of the specimens exhibiting much more dentine exposure than the lingual cusps. The occlusal surface form of the more severely worn first molars is partially concave to completely concave, resembling wear reported for other prehistoric agricultural populations (Smith 1984).

Generally, the chalcolithic Mehrgarh molars present a dental microwear pattern consisting of a relatively smooth polished surface with abundant small and medium pits,

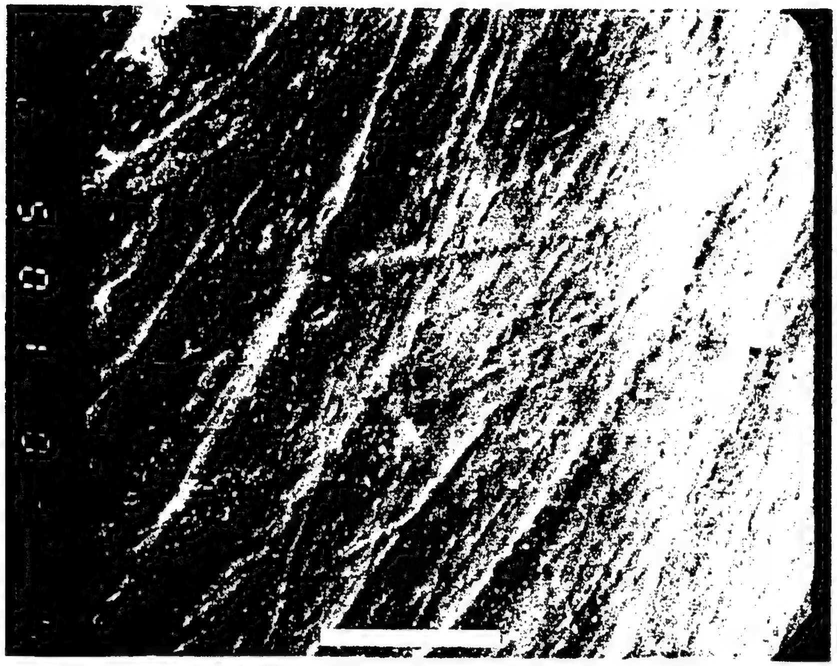


Figure 5.54. High Magnification (500x) Micrograph of Facet 1 from MR2-60-C2, Field 0619N. Scale equals 50 microns.

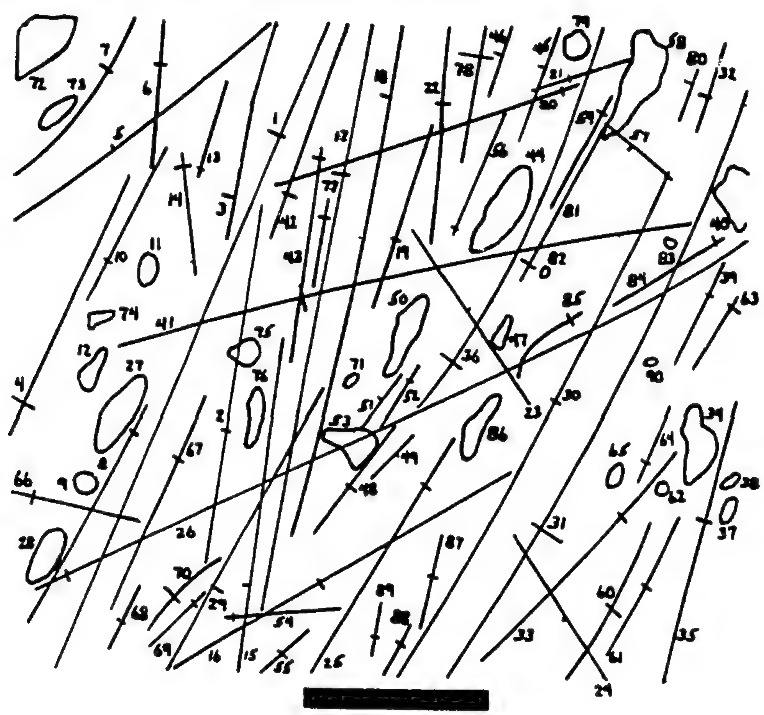


Figure 5.55. Acetate Transparency of 500x Field 0617N. Scale equals 50 microns.

and numerous long fine and wide scratches with sharp but also rough, angular margins and rough-appearing troughs (Table 5.2). Some fine scratches with rounded margins and smooth troughs are also present. Crisscrossed scratches occur, but less extensively than at Mahadaha. Scratches with rough troughs and sides are generally present on the Phase I facets of second molars from Mehrgarh. The general appearance of the enamel fabric of second molars is a rough textured surface, unlike the polished appearance of first molars. This difference in surface texture may be due to inherent differences in masticatory biomechanics between the first and second molars (Gordon 1980, 1982).

Generally, higher feature density is present and more morphological variability exists in the chalcolithic Mehrgarh microwear pattern than, for example, in that exhibited by Mahadaha permanent molars. For example, both the first and second permanent molars of individual MR2-46, an 11-12 year old child, were outliers with regard to the variability in scratch morphology and the relatively low frequency of pitting. In fact, they resembled each other more than each resembled homologous Mehrgarh teeth. This child also exhibited severe macroscopic tooth wear for its age (Table 5.1). Perhaps this child and other individuals in the chalcolithic Mehrgarh population had access to a more variable diet than was possible at Mahadaha. Alternatively, individual variation in masticatory biomechanics or non-masticatory behavior may have been responsible for the high variability of microwear patterns at Mehrgarh (MR2). It is also possible that this variability in microwear is an age-dependent phenomenon, because the two specimens that were most variable (MR2-46 and MR2-60) were the youngest in the chalcolithic Mehrgarh sample.

Evidence also exists for a sex difference between individuals when scratch morphologies are compared. In this case, the first molars from two male individuals (MR2-34, MR2-42) exhibit similar smooth scratch morphology, whereas the other first molars, two of which are identifiable as female, have scratches with a rougher morphology. This relationship also holds for the frequency of pitting, which is

considerably higher in males (see Chapter VII). However, the enamel fabrics of the two male specimens are different, with the enamel fabric of the MR2-34 specimen more similar to all other specimens. These qualitative differences in microwear patterns suggest a sex difference at chalcolithic Mehrgarh for food type, introduced dietary grit, food preparation and culinary behavior, or other factors (see Chapter VII).

Both the enamel polishing and the moderate amount of pitting evident in the early pottery-using agricultural population of Mehrgarh may be associated with the primary consumption of processed grains, such as wheat and barley, along with meat from domestic bovids (Meadow 1989). The generally high feature density, large number of pits, and perhaps the unique scratch morphology can be attributed to the use of stone grinding implements for processing the wide array of cultivated grains at Mehrgarh. The narrow scratches of the Mehrgarh molars are similar to the pattern reported by Teaford (1991) for late contact Georgia-Florida coast populations (late Altamaha period), but the latter groups exhibited fewer pits than the Mehrgarh (MR2) specimens (at least for the first molars). The agricultural Zuni of the American Southwest possessed dental microwear which showed much featureless surface roughening, and was coarse with broad scratches and large pits (Gordon 1986). In this case, a resemblance with Mehrgarh exists only with regard to the frequency of pitting. The absence of surface roughening (i.e., polishing) may be attributed to the addition of supplemental gathered vegetal foods to the Mehrgarh period III diet, and the pattern of striations may be due to the inclusion in the MR2 diet of meat from domestic bovids, with the possibility of contamination from grit. The ingestion and mastication of fibrous vegetal foodstuffs on a regular basis can contribute to the polishing of enamel tooth surfaces. However, botanical evidence for wild collected vegetal foods has not been reported from chalcolithic levels at Mehrgarh.

In contrast, very few striations appear on the molars of predynastic and dynastic Nubian and Egyptian populations, especially the upper first molars. Generally, the teeth of

these populations exhibited a polished appearance with few striations. Puech and his colleagues (1983) attribute this appearance to either the consumption of food with very fine abrasive particles or to chewing plant masticatories (e.g., papyrus) containing silica bodies (phytoliths). The Mehrgarh molars also have polished enamel occlusal surfaces, but the high frequency of long fine scratches found contrasts with the minimal scratching observed on the Egyptian teeth. Also, the consumption of phytolith-containing plant stems was not practiced at MR2, based on the botanical evidence (Meadow 1981, 1984, 1986, 1989).

Harappa

H87-37-36a

Moderate occlusal attrition (Molnar score = 3; Scott score = 14) of the lower first left molar tooth (H87 37 B1)[2] from an 11 year old of undetermined sex caused a marked reduction in crown height and flattening of the buccal cusps, and the hypoconulid (cusp 5). Moderate-sized patches of dentine exposure and prominent Phase I wear facets are present on cusps 1 and 3. Cusps 2 and 4 generally retain much of their height and natural morphology, however, although slight wear of cusp 2 has produced several small facets. Most of the central sulcus and lingual groove are present, while the buccal groove has been partially obliterated. A prominent buccal pit is present on this specimen. The oblique plane of wear on this specimen is oriented in a lingual-buccal direction, with a partially concave or semi-cupped form of wear.

The second left mandibular molar (H87 37 B2) from this juvenile is fully erupted, very lightly worn (Molnar score = 2; Scott score = 5), and exhibits a completely natural occlusal morphology. Cuspal crenulations and height have been retained in all cusps but cusp 1, which has a prominent shearing-phase wear facet on the mesial two-thirds of the

[2] H87 = site (Harappa) and the year of excavation; the second set of numbers is the feature number from which the specimen was recovered; the upper case letter is the alphabetical identifier for the molar specimen (see Table 3.1), and the accompanying number indicates whether the tooth is a first or second molar.

occlusal-buccal margin. The location of this wear facet is partially due to the fact that the tooth is tilted about 40 degrees lingually from the longitudinal axis.

<u>H87-60-46a-32</u>

Isolated lower right first and second molars (H87 60 K1; H87 60 K2) were recovered in a secondary burial context. These teeth were derived from a juvenile between 11-15 years of age, based on the attrition of the first molar and complete eruption of an unworn second molar (Scott and Symons 1982; Ubelaker 1978). The general pattern of attrition consists of an oblique wear plane oriented in a lingual-buccal direction with a partially concave occlusal surface. The buccal cusps and cusp 5 of the first molar are well worn, reduced in height, and partially flattened, with a small patch of exposed dentine on the flattened apex of cusp 1 (Molnar score= 2; Scott score = 10). Although cusps 2 and 4 retain much of their height, attrition has produced shearing facets on their buccal surfaces and obliterated many of the crenulations and other morphological features. Prominent shearing and crushing-grinding facets are present on cusps 1, 3, and 5. Facet 1 on cusp 1 is ovoid with a planar to convex surface, but in the absence of facet 2 is a platform of enamel with a strongly convex surface at the occlusal-buccal margin. Facet 6 is present on cusp 3 and is a 2-dimensional planar to concave feature on the enamel surface. The tooth retains a very prominent cruciate fissure system, of which only the mesial arm of the central sulcus is partially obliterated by wear. A moderate-sized buccal pit is also present on the tooth.

The second molar exhibits a completely natural form and an absence of any attrition on the occlusal surface (Molnar score = 1; Scott score = 4). Cusps are well formed, and the complex occlusal surface morphology includes numerous cuspal crenulations and a deep and well defined cruciate fissure system. Also present is a very large and deep buccal pit.

H87-60-46a-36

The lower left first molar (H87 60 D1) from this young adult female exhibits moderately severe attrition (Molnar score = 4; Scott score = 19), with an oblique lingual-buccal direction and a flat occlusal surface form (Molnar 1971). The height of all cusps has been reduced and much of the occlusal morphology has been obliterated. While the buccal groove has also been obliterated by wear, the central and lingual grooves have been retained, due in part to their great depth. A large patch of dentine is present on cusp 1 and cusp 3, while a pinprick of exposed dentine is present on each of the lingual cusps. Observation of the tooth through a hand lens reveals a thin band of Phase I wear facets along the entire occlusal-buccal margin. In addition, crushing and grinding (Phase II) facets surround the patches of dentine on the buccal cusps.

The light degree of occlusal wear (Molnar score = 2; Scott score = 10) on the lower left second molar (H87 60 D2) of this specimen has produced only slight reduction in height of cusps 1 and 3. These cusps retain a rounded shape, but much of the cuspal morphology has been obliterated by wear, resulting in very large flat to plano-convex shearing and crushing-grinding facets. The Phase I facets extend onto the buccal surface of the tooth to a level below the apical margin of the large buccal pit, which has been slightly enlarged by the concentration of occlusal wear on the buccal surface. This abnormal wear pattern is a result of a lingualward 15 degree angular rotation of the tooth in its alveolus with respect to the first molar. Also as a result of this rotation, occlusal wear of the lingual cusps is slight and much of the natural form has been retained. Central and lingual grooves are present, and a large fossa is located in the central groove near the occlusal-mesial margin. The general pattern of wear on this specimen consists of a completely concave form with an oblique lingual-buccal direction (Molnar 1971).

<u>H87-72-49b-1</u>

The lower left first molar (H87 72 E1) of this adult female individual exhibits a moderate degree of attrition (Molnar score = 3; Scott score = 17), which has produced a partially concave occlusal surface with the occlusal plane oriented in an oblique lingual-buccal direction. Much of the natural height of the lingual cusps has been retained, although the slight wear has partially obliterated their morphology. The more heavily worn buccal cusps have been almost completely flattened, resulting in exposure of a large patch of dentine on both cusps 1 and 3. Large planar to plano-convex shearing facets, including facets 1, 2 and 6, are present along the occlusal-buccal margin of these cusps. The central sulcus, lingual groove and part of the buccal groove are present, as well as a prominent buccal pit.

The slight to moderate attrition of the second left lower molar (H87 72 E2) of this individual has partially obliterated the morphology of cusp 2, partially flattened cusp 4, and completely flattened the buccal cusps. However, dentine exposure is absent on the occlusal surface of this tooth. The wear has also obliterated the distal portion of the central sulcus, and portions of the lingual and buccal grooves. Very prominent concave and convex shearing facets are present along the occlusal-buccal margin. Facets 1 and 6, on cusps 1 and 3 respectively, extend onto the buccal surface to approximately one-half the depth of the large buccal pit. The general pattern of wear on the tooth consists of a completely cupped occlusal surface, and the oblique plane of wear is oriented in a lingual-buccal direction.

<u>H87-85-49g-1</u>

Moderately severe attrition (Molnar score = 4; Scott score = 19) of the first right lower molar (H87 85 G1) from this adult female individual has flattened cusps 1, 3 and 5, and scalloped the buccal surface of cusps 2 and 4. The tooth is inclined 15 degrees distally

from its normal vertical position in the alveolus. As a consequence of wear on this inclined occlusal surface, a large patch of dentine has been exposed on cusps 1 and 2, while smaller dentine exposure occurs on the other cusps. However, the plane of occlusal wear is oblique and oriented in a lingual-buccal direction, while the form of wear is partially concave (Molnar 1971). Much of the occlusal morphology has been obliterated to an extent that only the lingual groove and distal portion of the central groove are intact. Cusp 1 facets 1 and 2 have a narrow and slightly convex shape, and the large facet 6 on cusp 3 has a strongly convex surface.

The second lower right molar (H87 85 G2) of this individual is mildly worn (Molnar score = 2; Scott score = 10), resulting in a completely concave occlusal surface and a wear plane that is oriented obliquely in a buccolingual direction (Molnar 1971). Although all cusps retain much of their original height, very large wear facets are present on cusps 1, 3 and 4 and exposed dentine is absent from the occlusal surface. Shearing facets 1 and 6 possess a concave surface. The central, lingual and buccal grooves are quite deep on this specimen and unaffected by the attrition.

The lower left first molar (H87 85 L1) from this individual exhibits a pattern of wear similar to its antimere (Molnar score = 4; Scott score = 17). The oblique occlusal wear plane is oriented in a lingual-buccal direction and a partially concave occlusal surface is present. The height of cusps 2 and 4 has been slightly reduced by the wear and exhibit small patches of dentine exposure, while cusps 1, 3 and 5 have been completely flattened. A large patch of dentine has been exposed on cusp 1. The large facet 1 on this cusp possesses a shallowly inclined slightly concave surface, and facet 2 consists of a narrow convex band of worn enamel. Much of the occlusal morphology has been obliterated by the wear, including the buccal groove and portions of the central sulcus. A very small buccal pit is also present on this specimen.

The pattern and degree of wear (Molnar score = 2; Scott score = 11) on the second

lower left molar (H87 85 L2) is also similar to its antimere with the exception of the direction of the occlusal wear plane, which is obliquely inclined in a lingual-buccal direction. As with the antimere, large shearing and crushing-grinding facets are present on all of the cusps, which with the exception of cusp 4 are slightly reduced in height and rounded. Facet 1 on cusp 1 is large and markedly concave. However, in the absence of facet 2 is a platform of enamel with a strongly convex surface at the occlusal-buccal margin, which also is inclined cervically at the mesiobuccal corner of the cusp. Deep central and lingual grooves are present, but the buccal groove is almost completely obliterated by the wear. In addition, the tooth exhibits a lingualward torsomolar rotation of approximately 70 degrees.

<u>H87-145-156a-1</u>

The lower right first molar (H87 145 AA1) from this female young adult was the first specimen from which dental impressions were collected during the 1988 Harappa field season. A completely concave form of attrition and a lingual-buccal oriented wear plane were observed on this specimen. The considerable amount of attrition (Molnar score = 3; Scott score = 20) has resulted in the diminution of the height of all cusps, with cusps 1 and 5 affected to the greatest degree. Large but discrete patches of dentine have been exposed on all but cusp 2, on which a pinprick size dentine exposure and large wear facet were observed. Much of the central and buccal grooves have been worn away and the normal cuspal morphology has been obliterated. Phase I wear facets, including facets 1 and 6, were observed along the buccal-occlusal margins of cusps 1 and 3, respectively.

The field of microscopic analysis on the slightly convex surface of facet 1 is located at the approximate center mesiodistally, but near the buccal-occlusal margin of the facet. A high magnification SEM micrograph taken from facet 1 is illustrated in Figure 5.56 (4515), a field produced where the plane of the facet was inclined at a moderate angle of incidence

(15 degrees) relative to the axis of the SEM electron beam. Visible in the micrograph are several paired long buccolingual scratches, oriented left to right, respectively. Other variable length transverse scratches are oriented mesiobuccal-distolingual (lower left to upper right, respectively). Several medium-sized pits are also visible. Figure 5.57 graphically illustrates the microwear features present on normal field 4511, from which feature measurements were collected for quantitative analysis (discussed in chapter VI). Morphologically, most scratches possess moderately rough margins interspersed with smoothly rounded segments. Some of the scratches exhibit rough troughs, but smooth troughs are also present on a few scratches. Generally, the microwear pattern of this facet consists of a moderate number of thin and medium-width scratches, in combination with a relatively high proportion of pitting. This specimen is somewhat of an outlier compared with other Harappa homologues, in that it exhibits a lower feature density and an enamel fabric with a more roughened surface. However, both of these conditions may be due to caliche deposits as a result of diagenetic alteration of the tooth.

The moderate attrition (Molnar score = 3; Scott score = 16) on the second right lower molar from this individual (H87 145 AA2) has produced an oblique lingual-buccal oriented wear plane, in which the occlusal surface has a completely concave form. Cusps 1 and 3 are worn completely flat, cusp 2 nearly so, while cusp 4 is partially rounded and retains some of the original morphology. Portions of the mesial arm of the central groove and the buccal groove have been obliterated. A large patch of dentine is exposed on cusp 1, and dentinal pits are present on cusp 3. The prominent shearing facet 1 has a slightly concave surface, but its leading (buccal) edge is convex. Shearing facets 2 and 6 are smaller and exhibit convex surfaces.

The field of SEM analysis, selected for quantitative analysis, is centered buccolingually on facet 1 and close to the distal end near the buccal pit. The micrograph illustrated in Figure 5.58 (4615) is taken from a strongly tilted (25 degrees) field at this

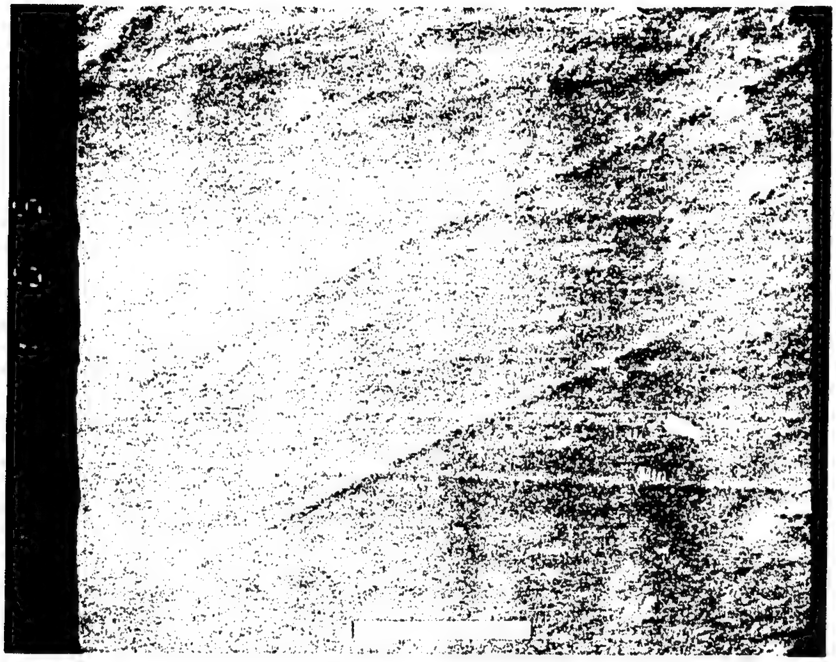


Figure 5.56. High Magnification (500x) Micrograph of Facet 1 from H87-145-156a-1-AA1, Field 4515. Scale equals 50 microns.

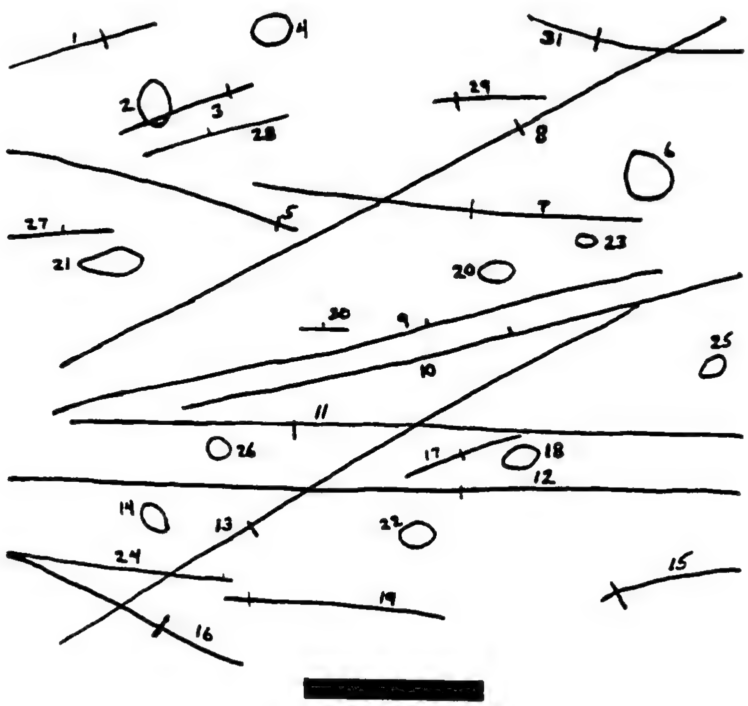


Figure 5.57. Acetate Transparency of 500x Field 4511. Scale equals 50 microns.

location. Visible are several thin to medium-width transverse scratches, which are oriented approximately in a mesiobuccal-distolingual direction (lower left to upper right, respectively). Present also are scratches oriented roughly at a right angle to these. A few vertical scratches are oriented mesiodistally (bottom to top, respectively). Many small to large pits and gouge-like features are also present throughout the field. In fact, the high relative proportion of pits on this specimen field is unusual, when compared to frequencies for the other Harappa homologues (see chap. VI). The types of features, and their orientations, are graphically illustrated in Figure 5.59, an acetate transparency taken from normal field 4611. Morphologically, most scratches possess sharp smooth margins and smooth sides, although some of the wide scratches have segments with rough sides and margins. The majority of scratches also possess smooth troughs. Generally, the microwear pattern consists of a somewhat roughened surface overlying a smooth and polished enamel fabric.

A similar microwear pattern is displayed by an additional field from facet 1 (4614, not shown), taken several field widths mesial to fields 4611/4615 and near the occlusal-buccal margin of the facet. The microwear pattern characteristic of facet 6 on cusp 3 of this tooth (field 4665, not shown) consists of many scratches with fine to medium-widths and mesiodistal orientations, and many medium pits.

<u>H88-191-185f-98</u>

Occlusal attrition of the first right mandibular molar (H88 191 BB1) from this young adult male has resulted in an oblique (lingual to buccal) wear plane in which the occlusal surface form is completely concave. Tilting of the tooth distally in its alveolus has also resulted in a mesiodistal tilt to the occlusal plane. The molar is worn to a considerable degree (Molnar score = 4; Scott score = 19), leaving only cusp 2 with a rounded form. Cusps 1 and 3 are completely flattened, and cusp 4 nearly so, with dentine exposure of

Figure 5.58. High Magnification (500x) Micrograph of Facet 1 from H87-145-156a-1-AA2, Field 4615. Scale equals 50 microns.

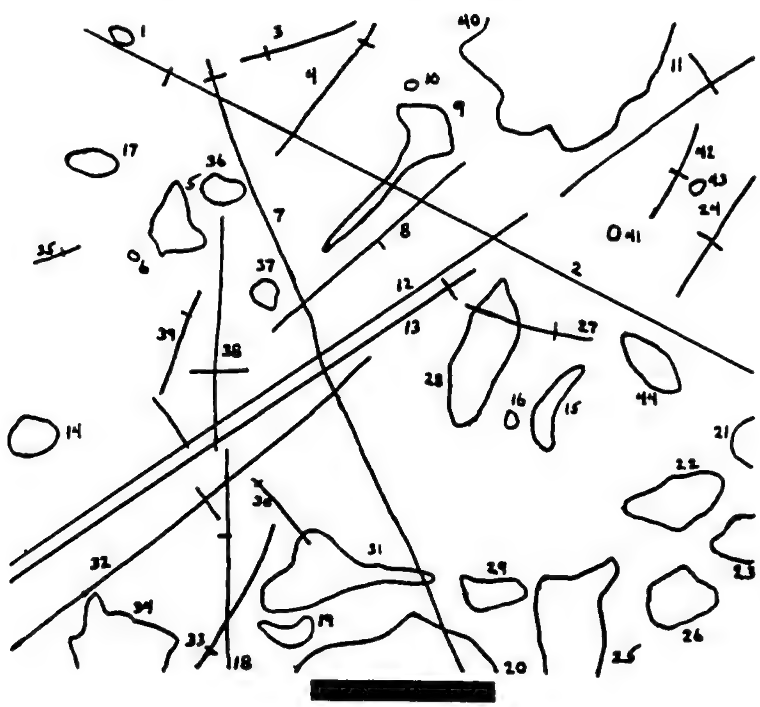


Figure 5.59. Acetate Transparency of 500x Field 4611. Scale equals 50 microns.

varying degree on all cusps. The attrition has also partially obliterated the distal and mesial portions of the central sulcus as well as part of the buccal groove. Low magnification examination of the occlusal surface revealed the presence of Phase I facets 1, 2 and 6. As described in Chapter IV, facet 6 is located on cusp 3, and on this specimen consists of a strongly convex rim of enamel along the occlusal-buccal margin.

The micrograph illustrated in Figure 5.60 (4715) is a strongly tilted (25 degree) high magnification field of facet 1. This very small facet possesses a planar surface, and exhibits many small and large pits in addition to a few buccolingual scratches, when examined at 15-30x. The SEM field is located approximately at the center (mesiodistally) of the facet and near the buccal margin with facet 2. Visible in the micrograph are several pits ranging in size from small to large. Also present are many short and long transverse scratches which are oriented in a predominantly buccolingual direction (lower left to upper right, respectively). Several short scratches are also oriented at roughly 180 degrees to these. These features are also graphically depicted in the acetate transparency from normal field 4711 (Figure 5.61). Several additional very fine scratches, with a buccolingual orientation, visible only in tilted field 4715 were added to the unmeasured count category.

With the exception of two wide scratches, the scratches on this field possess margins that are smoothly rounded but occasionally interspersed with rough portions. Many wide scratches possess rough troughs, while other wide and most fine scratches have smooth troughs. Examination of an additional microscopic field on facet 1 (4716, not shown) revealed a similar microwear pattern, with a preponderance of long scratches orientated in a buccolingual direction. Generally, the enamel fabric of facet 1 consists of a smooth polished surface, with a microwear pattern of many fine and wide buccolingually-oriented scratches and several predominantly medium-sized pits.

The second right molar of this specimen (H88 191 BB2) exhibits very light attrition (Molnar score = 2; Scott score = 7), although only cusp 2 retains its natural form. Cusps 3

Figure 5.60. High Magnification (500x) Micrograph of Facet 1 from H88-191-185f-98-BB1, Field 4715. Scale equals 50 microns.

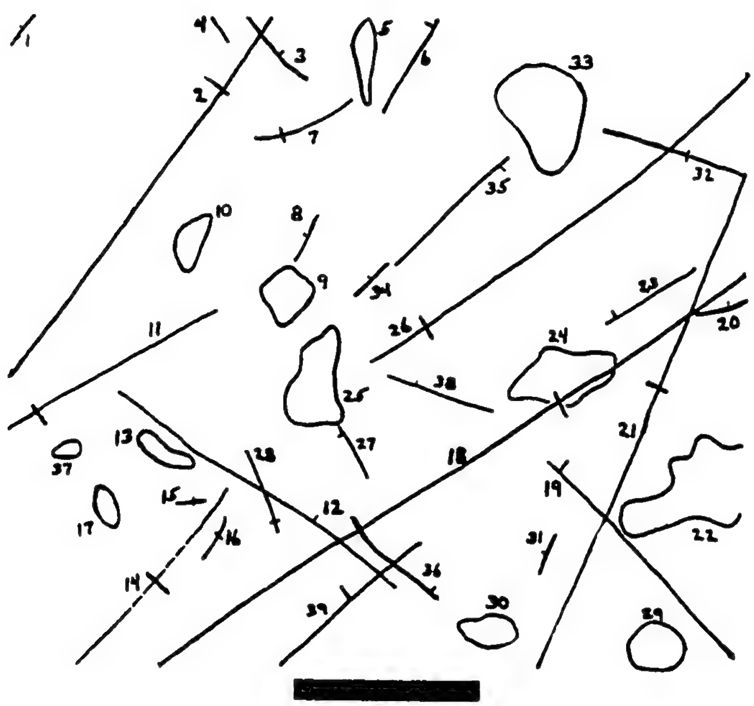


Figure 5.61. Acetate Transparency of 500x Field 4711. Scale equals 50 microns.

and 4 possess some of their original height but also exhibit large wear facets. Attrition on cusp 1 has worn it nearly flat and exposed a tiny patch of dentine near the former cusp apex. Crenulations remain on several cusps and the groove morphology is intact. The general direction of the wear plane is buccolingual and the form is partially concave.

Phase I facets are present on cusps 1 and 3, and the very small facet 1 possesses a slightly concave surface. Much pitting and a slight degree of scratching were visible when the facet surface was examined at low magnification with a light microscope. The strongly tilted (25 degree) field of high magnification (Figure 5.62, 4815) was located at the extreme lingual edge of facet 1 and adjacent mesially to the buccal groove. Many wide transverse scratches are orientated buccolingually (lower left to upper right, respectively), in addition to several vertical scratches that possess a more mesiodistal component to their orientation. Several additional short scratches at the lower left and upper right of the micrograph exhibit mesiodistal orientations (lower right to upper left, respectively). Also present are several small to medium-sized pits and a small number of very fine scratches. Figure 5.63, an acetate transparency from normal field 4811, graphically illustrates the microwear features in this field.

Morphologically, most very wide and some fine scratches exhibit rough troughs, sides and somewhat irregular margins, while most of the fine scratches exhibit a smoother morphology. The enamel fabric of this specimen exhibits some polishing but appears rougher than the M_1, due at least partially to the higher frequency of crisscrossed scratches on the M_2 field. An additional tilted field on facet 1 (4816, not shown), located approximately 600-800μm mesiobuccal to 4815, exhibits a similar microwear pattern, with a high density of long wide scratches and a few gouges and pits. Added to the unmeasured count category were several mostly fine scratches and a single pit visible on field 4815, but not on normal field 4811.

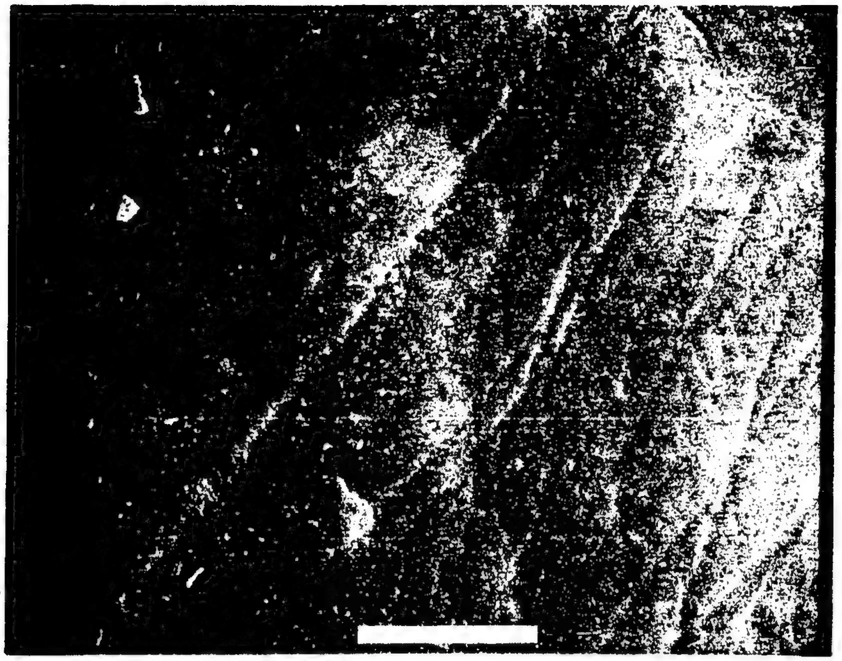


Figure 5.62. High Magnification (500x) Micrograph of Facet 1 from H88-191-185f-98-BB2, Field 4815. Scale equals 50 microns.

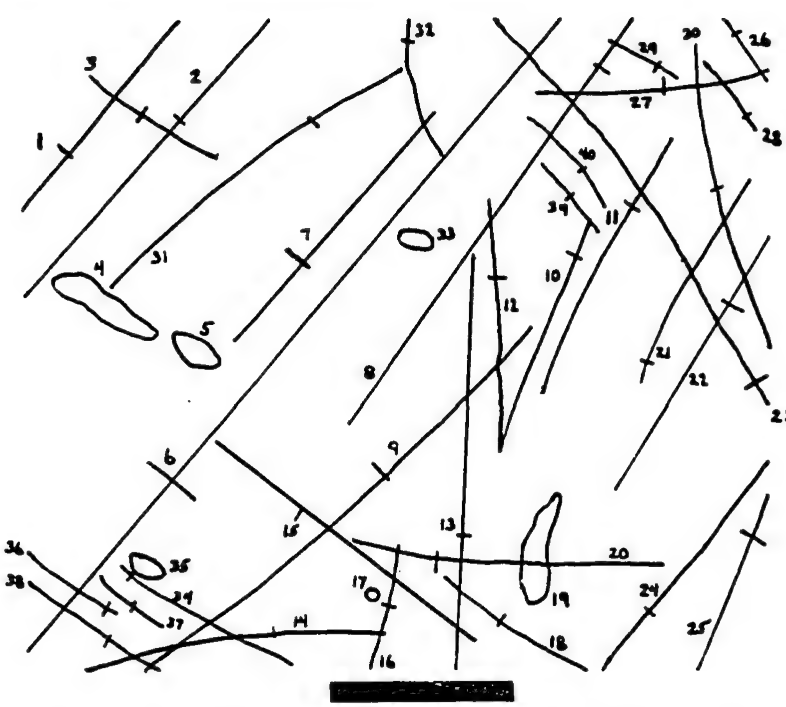


Figure 5.63. Acetate Transparency of 500x Field 4811. Scale equals 50 microns.

H88-200-203a-3

A completely concave form of attrition and a lingual-buccal oriented wear plane were observed on the first right mandibular molar (H88 200 CC1) from this individual, an adolescent male. The M_1 is tilted distally in its alveolus so that the entire occlusal surface is also inclined in a distal direction. The degree of attrition is moderately severe, with a Molnar score of 4 and a Scott score of 18. Cusps 2 and 4 retain some of their original height, although they are only slightly rounded, the crenulations have been removed, and a small patch of dentine is exposed on each cusp. The degree of wear on cusps 1, 3 and 5 is much greater, having produced a flattened form with large patches of dentine exposure (Figures 5.64, 5.65). The central sulcus has been partially obliterated, while the buccal groove has been almost completely obliterated. The result of the attrition on the buccal cusps is a flattened rim of enamel rather than actual Phase I facets on the buccal-occlusal margin of the tooth.

For the SEM analysis, a homologous area to facet 1 was selected on the enamel rim, consisting of a wide planar to convex surface with a lingual-buccal directional tilt. The high magnification field was located near the buccal-occlusal margin and at the distal end of the enamel rim of cusp 1 (Figure 5.64). As illustrated by the strongly tilted (25 degrees) micrograph displayed in Figure 5.66 (4915), many transverse buccolingually-oriented (lower left to upper right, respectively) scratches were present on the enamel surface. Most scratches are fine, but the widths of some scratches are relatively large. Also, at least some of the scratches possess moderately rough troughs, while smooth troughs are present on a few of the scratches, and sharp margins are generally not present. Figure 5.67 depicts a schematic drawing, taken from an acetate transparency of normal field 4911, of the microwear pattern exhibited by this specimen. Of note are the medium-sized pits at the center and upper right, and large gouges at the upper and lower margins of the field. The

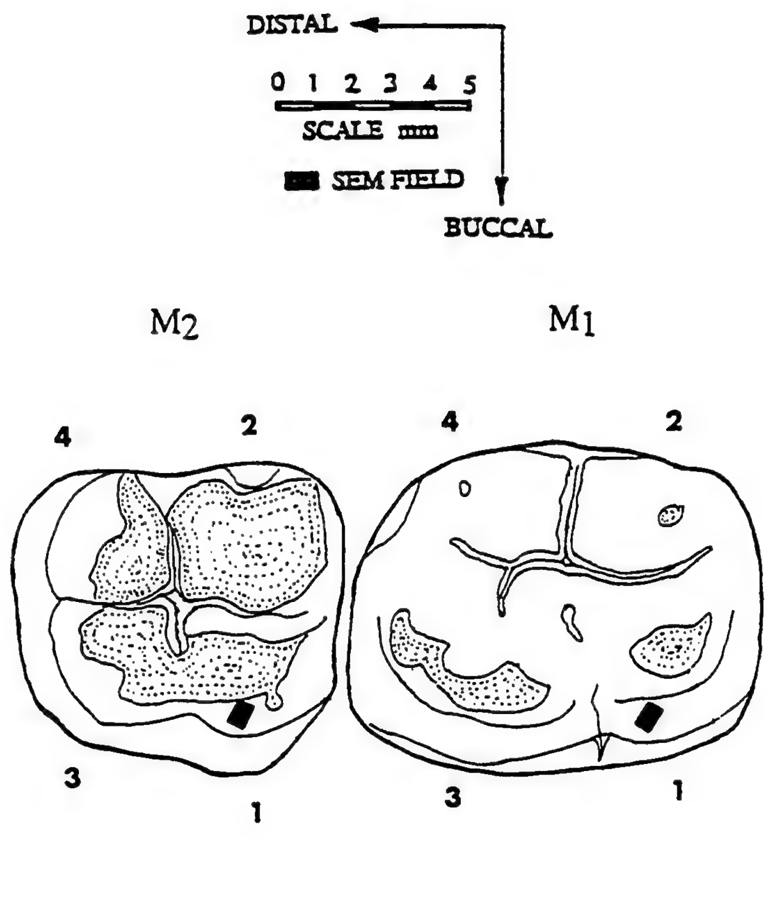


Figure 5.64. Drawing of RM_1 and RM_2 from Specimens H88-200-203a-3-CC1/CC2. Blackened Rectangles on Wear Facets Represent Position of SEM Fields.

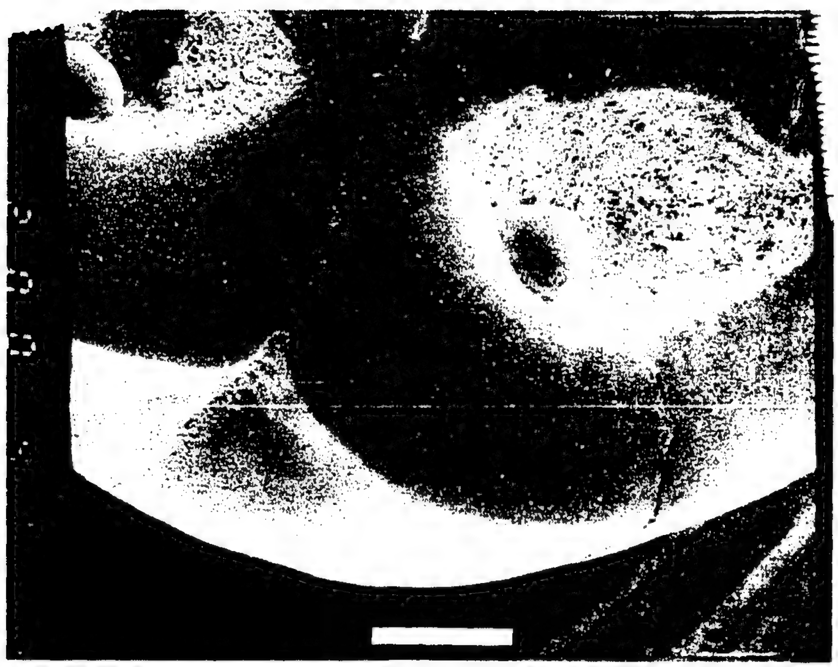


Figure 5.65. Low Magnification (20x) Micrograph of Cusp 1 from H88-200-203a-3-CC1, Field 4901. Scale equals 1000 microns.

enamel fabric of this specimen consists of a smooth polished surface, with a microwear pattern of predominantly long, fine and some wide unidirectional scratches, accompanied by little pitting. A similar microwear pattern, although with the addition of some mesiobuccal-distolingually oriented scratches, was observed on an additional field (4916, not shown) located several hundred micrometers mesial and buccal to field 4911/4915. A small number of fine scratches, faintly visible only on field 4915 at the center, upper left and lower right (Figure 5.66) were added to the unmeasured count category for this specimen.

The lower right second molar (H88 200 CC2) from Harappan individual H88-200 possesses a partially concave form of attrition, and the occlusal wear plane has a lingual-buccal direction. The moderate degree of attrition (Molnar score = 2; Scott score = 9) has resulted in the diminution of height and morphology for cusps 1 and 3, partially as a result of the lingual tilt of the tooth in its alveolus. The latter has caused the entire occlusal surface to be inclined lingually, and for attrition to be concentrated on more of the buccal surface of cusp 1 than normal. As a result, much of the original morphology of cusps 2 and 4 has been retained, along with the lingual and central grooves (Figures 5.64, 5.68). In addition to the attrition, much of the occlusal enamel suffers from heavy postmortem erosion, due possibly to diagenesis (see Chapter III). However, the enamel at the buccal-occlusal margin of cusp 1 is intact, and facets 1 and 2 are present. Facet 1 is very small and elliptical in shape, possesses a slightly concave surface, and is located on a wide convex rim of enamel. Under low magnification, large and small pits, and a few buccolingually-oriented scratches are visible.

The strongly tilted (25 degrees) high magnification field (5015, Figure 5.69) is located at the mesiolingual corner of the facet (Figure 5.64), and exhibits wide and fine scratches that are oriented in several directions. The majority of scratches are oriented buccolingually (lower left to upper right, respectively), others are oriented at roughly cross-

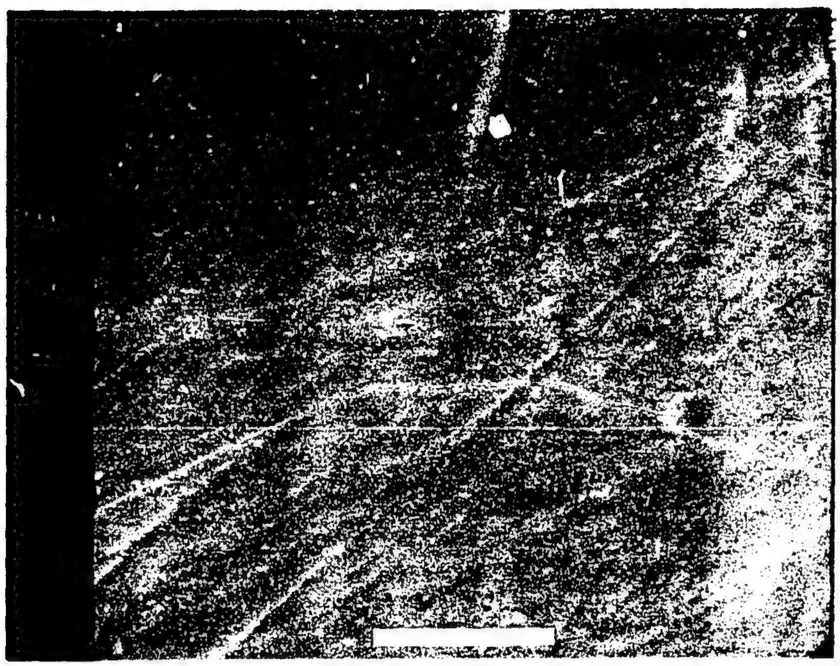


Figure 5.66. High Magnification (500x) Micrograph of Facet 1 from H88-200-203a-3-CC1, Field 4915. Scale equals 50 microns.

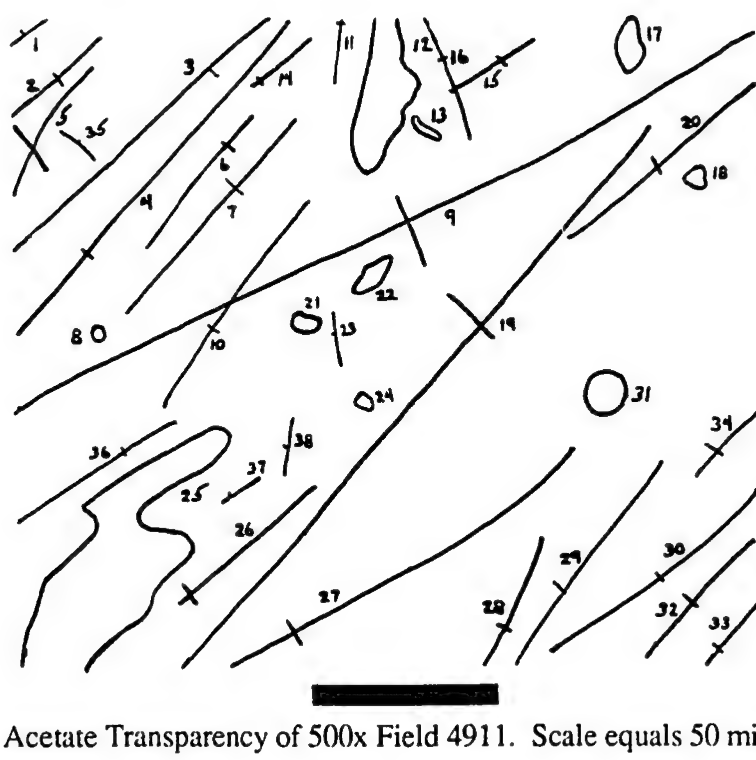


Figure 5.67. Acetate Transparency of 500x Field 4911. Scale equals 50 microns.

Figure 5.68. Low Magnification (20x) Micrograph of Cusp 1 from H88-200-203a-3-CC2, Field 5001. Scale equals 50 microns.

directions to these, while several vertical scratches have mesiobuccal-distolingual orientations. In addition, several small pits are concentrated at the center of the field. Several tiny circular pits at the lower center, near the vertical crack (postmortem), and at the upper margin of field 5015 appear to be casting defects. The microwear features are illustrated in Figure 5.70, taken from an acetate transparency of the normal field of facet 1 (5011). Additional short buccolingual scratches observed on tilted field 5015 were added to the unmeasured count for this specimen. Morphologically, the fine and wide scratches exhibit predominantly smooth troughs, sides and margins, the latter of which are less rounded but sharper than on other M_2's. A similar microwear pattern was observed on an additional field (5016, not shown), located about 400µm distal and 200µm buccal to fields 5011/5015. In general, the enamel fabric of the fields is similar to specimen H88 191 BB2, consisting of a polished surface that has been roughened by the many cross-directional scratches. Added to the unmeasured count category from field 5015 were many wide and some fine scratches.

A completely concave form of attrition and a lingual-buccal oriented wear plane were observed on the first left mandibular molar (H88 200 DD1) from this individual, as is true of the antimere of this tooth. The degree of occlusal attrition is also identical to the antimere (Molnar score = 4; Scott score = 18), with identical Scott wear scores recorded for each quadrant. The occlusal attrition has flattened all cusps but 2 and 4, the latter of which are reduced in height and exhibit large shearing facets on the buccal-facing surfaces. Large patches of exposed dentine are present on the buccal cusps, and these have united between cusps 3 and 5 to form a dentine lake. The wear has obliterated much of the occlusal morphology, with only portions of the central and lingual grooves present. Prominent shearing facets are present on the occlusal-buccal margin of the tooth. Facet 1 is large and has a planar surface, becoming strongly convex buccally. A small adjacent shearing facet (facet 2) on cusp 1 is ellipsoid in shape and exhibits a planar to slightly convex surface. A

Figure 5.69. High Magnification (500x) Micrograph of Facet 1 from H88-200-203a-3-CC2, Field 5015. Scale equals 50 microns.

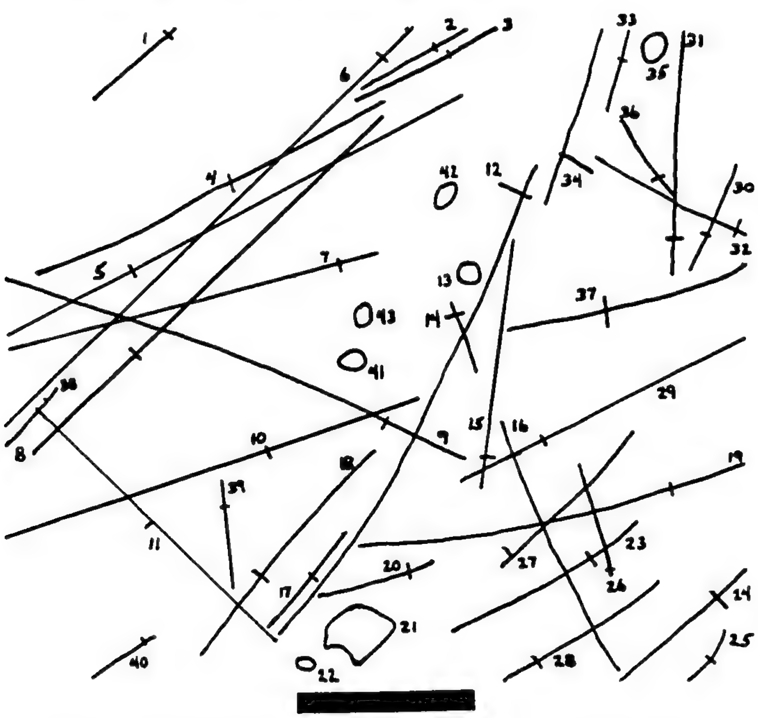


Figure 5.70. Acetate Transparency of 500x Field 5011. Scale equals 50 microns.

similar shearing facet (facet 6) is also located on cusp 3, immediately adjacent to the small buccal pit.

The large interproximal wear facet on the distal surface of the crown of this molar indicates that the left second molar was a fully erupted and functional tooth, which was lost postmortem and not recovered with the dental and gnathic remains of this individual. The impression taken of the first molar included the adjacent second permanent premolar. As with the first molar, attrition of this tooth was also moderately severe, resulting in loss of morphology on both cusps and flattening of the occlusal surface. A very small patch of dentine is exposed on the buccal cusp. Wear scores were not recorded for this premolar tooth.

The strongly tilted (25 degrees) high magnification field in Figure 5.71 (5126) is located at the far distant corner of facet 2 near its juncture with facet 1. Very slight foreshortening of this field, when compared with the "normal" field from this location, is probably attributable to the slight convexity of the facet surface. The microwear pattern consists of many fine and wide transverse scratches that are oriented in an approximately mesiobuccal-distolingual direction (lower left to upper right, respectively). A small number of vertical scratches in the lower right corner of the micrograph are oriented buccolingually (bottom to top, respectively). Morphologically, the fine and wide scratches exhibit predominantly smooth troughs, sides and margins, the latter of which are slightly rounded. The enamel fabric consists of a smoothly polished surface that has acquired a roughened appearance, due to the density of scratches and also due to the small particles of dust or caliche (the bright objects in the micrograph) present on the facet surface.

H88-197-194a-1

Occlusal attrition is complex on the first right lower molar (H88 197 EE1) from this young adult female, with a lingual-buccal direction and completely concave form on the

Figure 5.71. High Magnification (500x) Micrograph of Facet 2 from H88-200-203a-3-DD1, Field 5126. Scale equals 50 microns.

lingual facets, but with a flattened form and lingual-buccal direction on the buccal facets. The moderately severe attrition (Molnar score = 4, Scott score = 18) has resulted in a loss of most morphological characteristics of the lingual cusps, with the exposure of a small patch of dentine on cusp 2. The wear has been severe enough to produce a cupped form on the lingual cusps, obliteration of much of the central sulcus and buccal groove, and flattenning of the buccal cusps with the exposure of large dentinal patches on cusps 1 and 3 and a small dentinal patch on cusp 5. Very prominent flat-to-convex Phase I wear facets occur on the occlusal-buccal margin of the tooth. Facet 1 has a large planar surface and exhibits many small pits and buccolingual and transverse scratches under low (30x) magnification. Facet 6, a small planar Phase I facet, was mapped on cusp 3 in lieu of facet 2, which exhibited postmortem gouges and a large casting defect. Several large casting defects (positive bubble artifacts) were observed on the enamel surface and in the exposed dentine, but not on facet 1.

The micrograph illustrated in Figure 5.72 (5215) is a strongly tilted field taken at the mesial end near the buccal margin of facet 1. Visible are several long and many short buccolingual (lower left to upper right, respectively) scratches, and many short horizontal scratches with a more distobuccal-mesiolingual orientation (left to right, respectively). Most scratches are relatively wide and few scratches are present. Also visible are many small and medium-sized pits. The series of small (1-4μm) pits visible in the upper portion of Figure 5.72 were not analyzed, because they appeared to be casting defects. The microwear features are graphically illustrated in Figure 5.73, an acetate transparency from normal field 5211 (not shown). Added to the unmeasured count category for this specimen were a few small pits and several scratches, of fine and medium width, observed only on tilted field 5215. Morphologically, the margins of most scratches are smoothly rounded, interspersed with many rough portions. Some scratches possess rough and pitted troughs, while the troughs of a few scratches are smooth. Generally, the enamel fabric consists of a

smooth polished surface with a microwear pattern of many long and short wide, and fewer fine, scratches combined with a moderate degree of pitting. A very similar microwear pattern, although with fewer fine scratches, was observed on an additional field (5216, not shown) located at the center of facet 1.

The form and direction of occlusal attrition on the second lower right molar (H88 197 EE2) is similar to the M_1. A slightly lower degree of attrition was observed (Molnar score = 3; Scott score = 16), which produced moderate dentine exposure on all but cusp 4. Much of the cusp morphology and portions of the central and buccal grooves have been reduced. Both facets 1 and 2 are prominent, the former of which possesses a planar surface that is very narrow mesiodistally and is inclined distally toward the central sulcus. At low magnification, a few large and small pits and several transverse gouges or scratches were observed.

The micrograph illustrated in Figure 5.74 (5315) was taken from a strongly tilted field (25 degrees) located at the center of facet 1. Visible in the micrograph and in the graphical illustration from an acetate transparency of normal field 5311 (Figure 5.75) are fine and wide buccolingually-oriented scratches (lower left to upper right, respectively). The fine scratches are not as numerous as the wide ones. The more vertical scratches visible at the center and upper left of Figure 5.74 exhibit mesiobuccal-distolingual orientations (bottom to top, respectively). Some of the finer of these vertical scratches were actually more readily visible, but still quite faint, on normal field 5311 (not shown). An area of detritus, possibly from postmortem caliche deposits, at the left of center has obscured some of the features in this area. A very fine transverse crack of postmortem origin also is located at the upper left. Pitting is extensive on this specimen, with pits ranging in size from small to large. Included in the unmeasured count taken from field 5315 are several mostly medium-width scratches and a single medium pit.

Morphologically, most very wide and some fine scratches possess rough troughs,

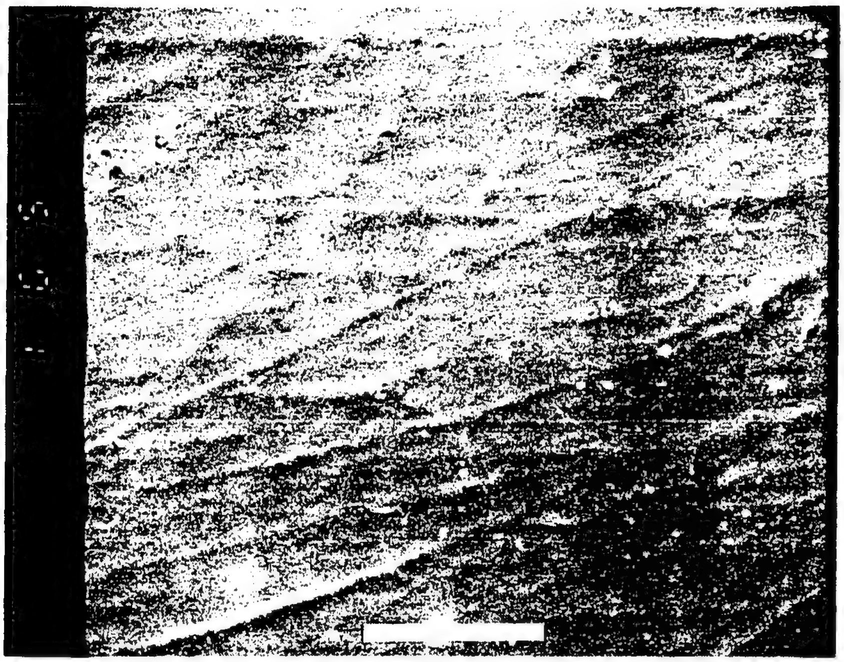


Figure 5.72. High Magnification (500x) Micrograph of Facet 1 from H88-197-194a-1-EE1, Field 5215. Scale equals 50 microns.

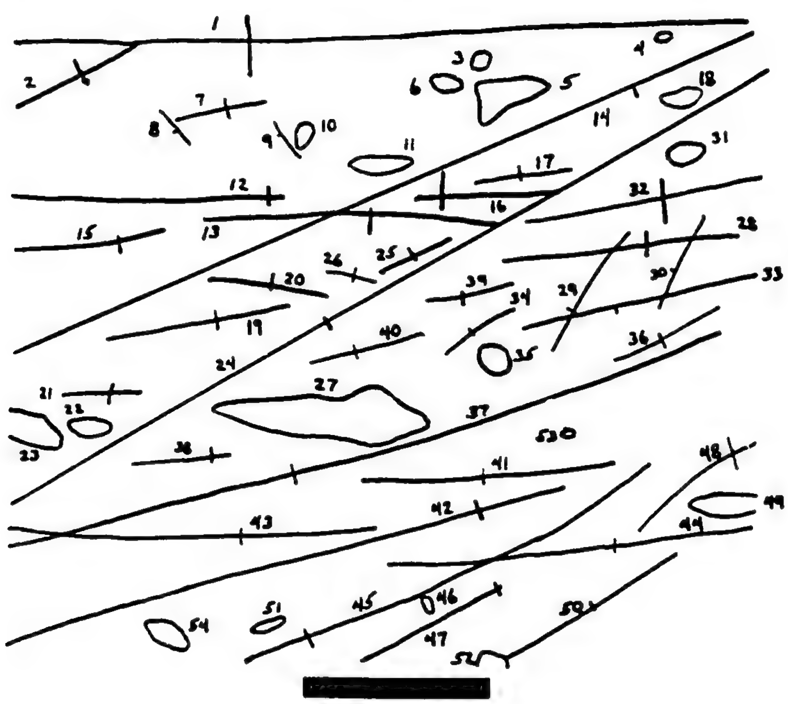


Figure 5.73. Acetate Transparency of 500x Field 5211. Scale equals 50 microns.

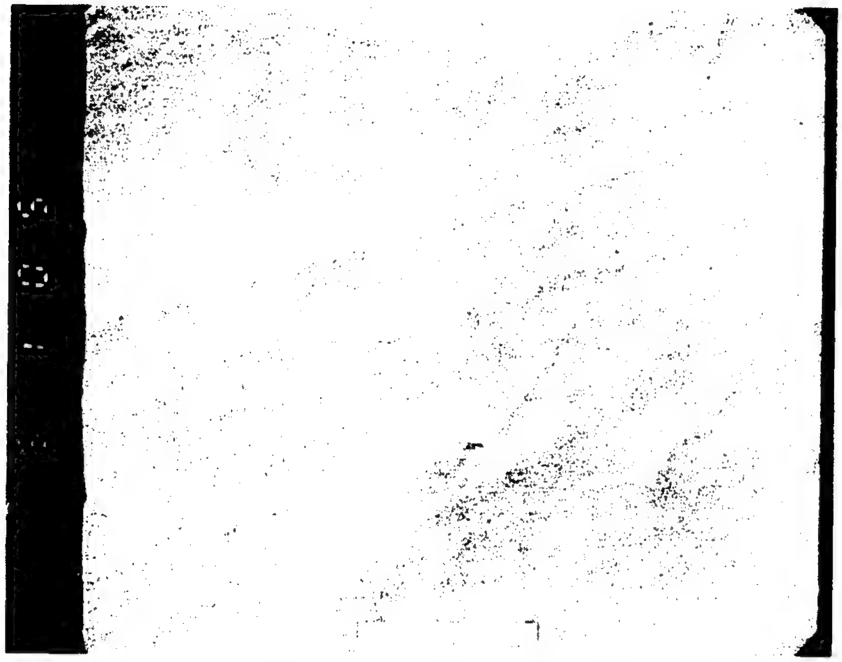


Figure 5.74. High Magnification (500x) Micrograph of Facet 1 from H88-197-194a-1-EE2, Field 5315. Scale equals 50 microns.

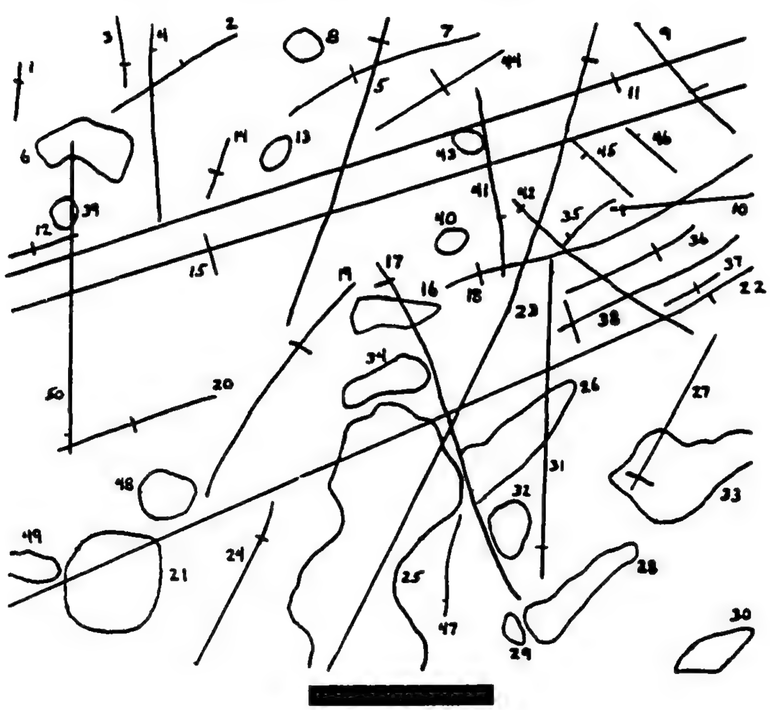


Figure 5.75. Acetate Transparency of 500x Field 5311. Scale equals 50 microns.

while many smooth-troughed fine scratches are also present. Most scratches possess rough sides with somewhat rough margins that appear intermediate between sharp and smooth. An additional tilted field (5316, not shown) located approximately 200µm lingual and 400µm mesial to fields 5311/5315 exhibits numerous fine and wide scratches and small to medium pits, a microwear pattern similar to that of the latter fields. Generally, the enamel fabric of facet 1 is somewhat rough with a microwear pattern of several fine and wide transverse to vertical scratches, interspersed with small to large pits.

Impressions and replicas were also made of left molar antimeres from individual H88-197-194a-1, which were analyzed for attrition and microwear. The lower first molar (H88 197 FF1) exhibits a very similar degree of wear to its antimere, with identical wear scores recorded for each cusp (Molnar score = 4; Scott score = 18). As with the antimere, this tooth exhibits a form of wear in which the entire occlusal surface is cupped and obliquely oriented in a lingual-buccal direction. Only the lingual edges of cusps 2 and 4 retain much of their original height, while most of the occlusal surface has been flattened and much of the occlusal morphology, including sulci, obliterated by the moderately severe wear. Large patches of dentine are exposed on all but cusp 4. Large shearing facets (facets 1 and 6) are present on both cusps 1 and 3 adjacent to a prominent buccal pit. The large facet 1 has a planar to slightly convex surface, while the much less prominent facet 2 has a strongly convex surface at the occlusal-buccal margin. Facet 6 on cusp 3 is very large and has a convex surface.

Illustrated in Figure 5.76 (5415) is a micrograph taken from a strongly tilted field located on facet 1 near its lingual edge and several hundred µm mesial from the buccal pit. The surface shown is slightly convex because of its position on the margin with a Phase II (grinding) facet. The convex surface together with the high degree of tilt have foreshortened the field slightly when compared with the "normal" field (5411, not shown). Visible are several prominent long horizontal scratches, orientated approximately

buccolingually (left to right, respectively), crisscrossing many fine vertical and fainter scratches, which have a mesiodistal orientation (top to bottom, respectively). The former scratches appear to be of more recent origin, judging by their prominence and the partial obliteration of some of the mesiodistal scratches. Scratch width is variable. Also visible are several small and medium-sized pits, some of which are associated with scratches. Several gouges are present at the left and upper portions of the field. Scratch morphology consists of rounded and moderately rough margins, and rough sides and troughs, especially for the wider scratches. The high density of features and crisscrossed nature of scratches has produced a very rough looking facet surface, although the underlying enamel fabric appears smoothly polished.

The degree of occlusal wear and the form and orientation of the wear plane on the lower left second molar (H88 197 FF2) are nearly identical to the antimere of this tooth (Molnar score = 3; Scott score = 16. However, wear on quadrant 1 is slightly greater (Scott score = 6) and on quadrant 4 is slightly less (Scott score = 2) than on the antimere. Cusp 1 has been flattened and the height of cusp 1 has been greatly reduced, while cusps 2 and 4 retain much of their original height at the occlusal-lingual margin but have been worn away on the buccal surfaces. A large patch of dentine is exposed on cusp 1, while cusp 3 has a smaller area of dentine exposure. Much of the occlusal morphology has been obliterated by the attrition, except for the lingual groove and portions of the central and buccal groove. The entire occlusal-buccal margin of the tooth is encompassed by a shearing facet, a strongly convex platform of enamel, but less surface area is involved than on the antimere. Although the facet surface is more-or-less contiguous, for analytical purposes facets 1 and 2 were considered to be located within the portion of the facet surface on cusp 1 and mesial to a shallow vertical groove on the buccal surface of the crown, a very slight expression of the buccal pit. Facet 6 was considered to be the portion of the wear platform located immediately adjacent distally to this groove.

The micrograph in Figure 5.77 (5515) was taken from a strongly tilted field (21 degrees) on the large cusp 1 shearing facet in an area homologous to facet 1. The location of the field is slightly mesial to the buccal depression and near the buccal margin of the facet. The rippled surface visible at the far left in the micrograph resembles unworn enamel prisms, indicating that this area of the field was located on the buccal surface of the tooth. Visible in the micrograph are many horizontal to slightly transverse scratches, which range in width from narrow to wide, and which exhibit a mesiobuccal-distolingual orientation (left to right, respectively). Several vertical to nearly vertical scratches (e.g. at upper right) are oriented more mesiodistally (top to bottom, respectively). A fine postmortem crack traverses the center of the field from lower left to upper right. Most scratches have rounded and moderately rough margins, and rough sides. Some of the finer scratches have smooth sharp-edged margins and smooth sides. Troughs of most scratches are smooth. Pitting is generally absent from this area of the facet. The enamel fabric consists of a smooth and polished surface that has a somewhat rough appearance due to the many crisscrossed scratches.

Summary of Dental Attrition and Microwear

In summary, the attrition observed on the occlusal surfaces of the Harappan molars is generally moderate, with the buccal cusps of most of the specimens exhibiting much more dentine exposure than the lingual cusps. The occlusal surface form of the more severely worn first molars of Harappans is completely concave. All first molars exhibit an oblique occlusal wear plane oriented in a lingual-buccal direction. The same is true for the second molars, except for several newly erupted teeth which possess a natural form, and four molars with oblique wear planes oriented in an opposite direction. As may be seen in Table 5.1, the mean Molnar scores for single antimeres of the first and second molars from the Harappa sample are 3.63 and 2.25, and mean Scott wear scores are 18.00 and 10.75,

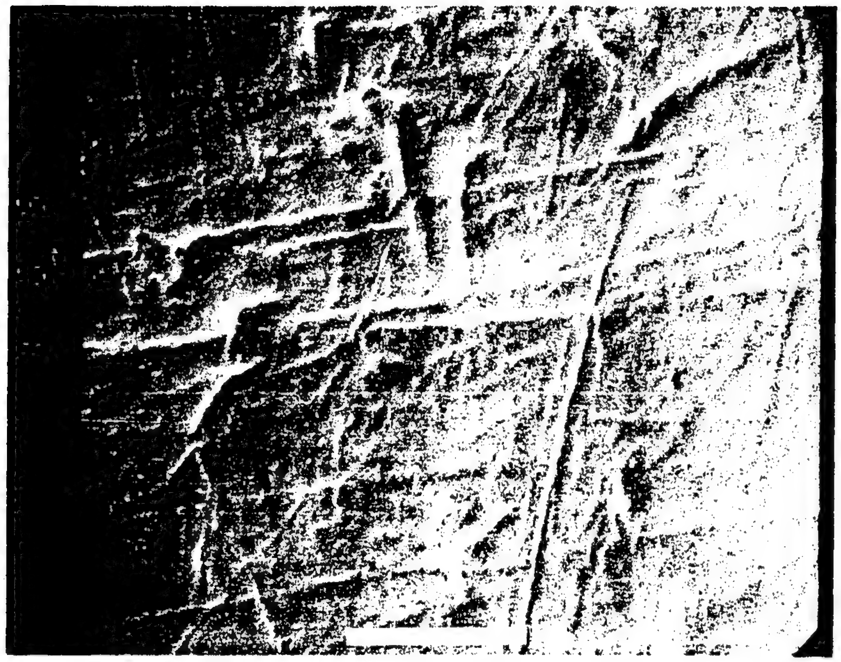


Figure 5.76. High Magnification (500x) Micrograph of Facet 1 from H88-197-194a-1-FF1, Field 5415. Scale equals 50 microns.

Figure 5.77. High Magnification (500x) Micrograph of Facet 1 from H88-197-194a-1-FF2, Field 5515. Scale equals 50 microns.

respectively. These specimens were selected for their moderate wear and do not necessarily represent the entire Harappa dental sample. Nevertheless, both the moderate degree and completely concave form of macroscopic wear exhibited by these Harappa molars resemble that of other prehistoric agricultural populations, whose diets generally consist of soft, sticky, high carbohydrate foods prepared from processed grains (Smith 1984).

In general, Harappan molars present a somewhat variable dental microwear pattern, consisting of long fine and wide buccolingually oriented scratches with moderately rough troughs (Table 5.2). Some scratches with smooth troughs are also present. Scratch margins are partially smooth and rounded, but mostly rough and slightly irregular. Sharp-margined scratches are generally absent. The scratch morphology of lower second molars is very similar to that of first molars, and both types of molars generally exhibit a moderate degree of pitting, with both medium and large pits present. A fair number of long scratches on the fields of second molars exhibit margins that are intermediate between sharp and rounded. This is especially true for the wider scratches. As with first molars, the second molars show moderate variation in the microwear pattern. In general, the enamel fabric of first molars consists of a smooth polished surface, but that of second molars has a slightly rougher appearance with more crisscrossed scratches.

The enamel polishing and the high frequency of pitting are associated with the consumption predominantly of processed grains, such as wheat and barley, with the addition of meat from domestic pig and domestic bovids, such as cattle, sheep, and goat (Meadow 1989; Meadow 1991a). Botanical evidence for rice, peas, figs, dates, melons, mangos, pomegranates, bananas (?), and sesamum have also been recovered from Harappan sites (Allchin and Allchin 1982; Fairservis 1975; Wheeler 1968), although many of these plants have not been identified at Harappa itself. In addition to the carbonized seeds of wheat and barley, also recovered from Harappa were seeds of legumes, a variety

of wild grasses, and Zizyphus sp. (Dales and Kenoyer, n.d.-a). At Harappa, groundstone querns and mullers of fine to coarse-grained material were used to grind the cereal grains into flour. The high frequency of pitting and perhaps the unique scratch pattern can be attributed to the use of such grinding implements. Possibly, Harappa residents were ingesting abrasive particles or hard objects through their diet as a result of the use of such implements (see Chapter VII).

It is possible that the absence of surface roughening, at least for first molars, is attributable to the addition of supplemental wild, gathered vegetal foods to the mature Harappan diet. In contrast, the ingestion and mastication of fibrous vegetal foods on a regular basis would have contributed to the polishing of enamel tooth surfaces. The moderate variability in qualitative measures of dental microwear may reflect the recent evidence for wild as well as domestic fauna present in different occupation areas at Harappa (Dales and Kenoyer, n.d.-a; Meadow 1991a). The microwear variability may represent differential access by Harappan individuals to meat from domestic or wild animals, or indicate that individual variation existed for methods of food preparation (see Chapter VII).

CHAPTER VI

RESULTS: QUANTITATIVE ANALYSIS

Introduction

I present the results of my quantitative analyses of the attrition and microwear data in this chapter. Included in this presentation are tables of raw values, as well as descriptive statistics, of all quantitative variables. All means and standard deviations are reported in terms of the original units. However, as described previously in Chapter IV, specimen (subject) mean values for all variables were transformed prior to performing parametric statistical analyses. The following transformation procedures were used, as recommended by Zar (1984) and Sokal and Rohlf (1969): the arcsin transformation of all ratio (frequency) data; square root of feature counts (numbers); and $\log_{10}$ (common log) of metric data. Univariate statistical procedures used in this study include primarily the Student's t-test, single-factor analysis of variance (ANOVA), and the Tukey HSD test, a multiple comparison procedure using sample means (Zar 1984). Normal probability tests were used to examine the distribution of the raw data for each variable (Velleman 1988; Vos, personal communication 1992). Since few cases were found that substantially violated the assumption of normality required for parametric analyses (Zar 1984), nonparametric procedures such as the Mann-Whitney or Kruskal-Wallis tests were not used in the analyses.

Listed in the left-hand column of Tables 6.1 and 6.2 are the metric and derived variables collected from micrographic fields on first and second molars, respectively. As discussed in Chapter IV, the archaeological groups were compared using only homologous molar teeth. In other words, the sample was subdivided into two nearly equal size

Table 6.1. Group Means and Standard Deviations of Microwear Variables for Mandibular First Molar Teeth from South Asian Archaeological Sites

Variables	Mahadaha (MDH)	Mehrgarh (MR3)	Mehrgarh (MR2)	Harappa (H88)
Number of features	41.60 ± 14.91	85.00 ± 26.87	67.00 ± 12.71	40.50 ± 9.68
Grand total number of features	59.60 ± 12.34	109.00 ± 31.11	96.00 ± 17.69	52.50 ± 11.45
Number of pits	11.20 ± 7.50	16.00 ± 7.07	17.80 ± 15.12	12.75 ± 3.59
Grand total number of pits	15.60 ± 7.47	17.50 ± 7.78	20.60 ± 7.57	15.00 ± 5.48
Number of scratches	30.40 ± 10.55	69.00 ± 19.80	49.20 ± 8.29	27.75 ± 6.55
Grand total number of scratches	44.00 ± 9.75	91.50 ± 23.34	75.40 ± 11.93	37.50 ± 6.95
Percentage of total pits (%)	26.08 ± 11.39	18.43 ± 2.49	26.29 ± 3.71	31.58 ± 4.25
Percentage of grand total pits (%)	25.59 ± 9.76	51.68 ± 2.66	20.99 ± 5.06	28.18 ± 5.04
Percentage of total scratches (%)	73.92 ± 11.39	81.57 ± 2.49	73.71 ± 3.71	68.42 ± 4.25
Percentage of grand total scratches (%)	74.41 ± 9.76	84.33 ± 2.66	79.01 ± 5.06	71.83 ± 5.04
Scratch width (µm)	3.04 ± 0.99	2.77 ± 0.59	3.85 ± 0.78	4.59 ± 0.82
Pit width (µm)	6.61 ± 2.30	5.94 ± 0.99	6.91 ± 1.86	8.67 ± 3.01
Number of sm. pits ≤ 5 µm in width	5.60 ± 4.98	10.00 ± 4.24	7.40 ± 4.16	4.50 ± 2.65
Number of lg. pits > 5 µm in width	5.60 ± 4.04	6.00 ± 2.83	10.40 ± 5.03	8.25 ± 2.36
Number of sm. scratches ≤ 2 µm in width	14.00 ± 7.84	32.50 ± 23.34	12.80 ± 3.35	4.25 ± 3.40
Number of lg. scratches > 2 µm in width	16.40 ± 9.53	36.50 ± 3.54	36.40 ± 7.57	23.50 ± 6.86
Percentage of sm. pits ≤ 5 µm in width (%)	12.00 ± 7.61	11.55 ± 1.34	10.90 ± 5.10	10.70 ± 4.30
Percentage of lg. pits > 5µm in width (%)	14.20 ± 8.37	6.90 ± 1.13	15.40 ± 6.89	20.78 ± 6.09
Percentage of sm. scratches ≤ 2µm in width (%)	36.04 ± 18.37	35.65 ± 16.19	19.40 ± 5.16	10.60 ± 8.87
Percentage of lg. scratches > 2µm in width (%)	37.90 ± 10.81	45.90 ± 18.67	54.32 ± 6.04	57.95 ± 7.89
Width of sm. pits ≤ 5µm	3.33 ± 1.18	3.61 ± 0.27	3.45 ± 0.43	3.84 ± 0.57
Width of lg. pits > 5µm	10.54 ± 1.65	9.42 ± 2.59	9.08 ± 1.74	11.27 ± 3.70
Width of sm. scratches ≤ 2µm	1.35 ± 0.12	1.28 -------	1.30 ± 0.07	1.25 ± 0.10
Width of lg. scratches > 2µm	4.32 ± 0.86	3.93 ± 0.05	4.75 ± 0.87	5.17 ± 0.64

Note: Values are in original (untransformed) units, reported as mean ± standard deviation.
Sample size (n) for MDH = 5, MR3 = 2, MR2 = 5, H88 = 4.

Table 6.2. Group Means and Standard Deviations of Microwear Variables for Mandibular Second Molar Teeth from South Asian Achaeological Sites

Variables	Mahadaha (MDH)	Mehrgarh (MR3)	Mehrgarh (MR2)	Harappa (H88)
Number of features	31.40 ± 6.69	80.00 ------	70.40 ± 17.04	44.25 ± 4.19
Grand total number of features	50.60 ± 11.82	89.00 ------	96.00 ± 21.30	57.50 ± 7.00
Number of pits	6.00 ± 3.94	21.00 ------	15.80 ± 6.22	14.25 ± 9.54
Grand total number of pits	11.60 ± 4.51	24.00 ------	19.00 ± 7.81	16.25 ± 9.91
Number of scratches	25.40 ± 4.98	56.00 ------	54.60 ± 12.03	30.00 ± 8.17
Grand total number of scratches	39.00 ± 7.97	65.00 ------	77.00 ± 15.43	41.25 ± 11.87
Percentage of total pits (%)	18.66 ± 10.27	30.00 ------	22.34 ± 4.64	31.59 ± 20.70
Percentage of grand total pits (%)	22.52 ± 4.33	26.97 ------	19.39 ± 4.37	28.39 ± 17.96
Percentage of total scratches (%)	81.34 ± 10.27	70.00 ------	77.66 ± 4.64	68.41 ± 20.70
Percentage of grand total scratches (%)	77.48 ± 4.33	73.03 ------	80.61 ± 4.37	71.61 ± 17.96
Scratch width (µm)	2.90 ± 0.70	2.70 ------	3.20 ± 0.60	4.70 ± 1.10
Pit width (µm)	4.50 ± 2.10	7.50 ------	7.20 ± 1.90	9.10 ± 3.70
Number of sm. pits ≤ 5 µm in width	4.20 ± 3.56	5.00 ------	6.20 ± 3.90	3.50 ± 2.08
Number of lg. pits > 5 µm in width	1.80 ± 1.48	19.00 ------	9.80 ± 3.63	10.75 ± 9.03
Number of sm. scratches ≤ 2 µm in width	9.60 ± 5.51	29.00 ------	18.00 ± 5.15	4.25 ± 3.86
Number of lg. scratches > 2 µm in width	15.80 ± 3.27	27.00 ------	36.40 ± 12.28	25.75 ± 7.68
Percentage of sm. pits ≤ 5 µm in width (%)	13.40 ± 11.93	6.30 ------	8.70 ± 4.27	8.10 ± 4.81
Percentage of lg. pits > 5µm in width	5.44 ± 3.38	23.80 ------	13.64 ± 2.40	23.50 ± 19.34
Percentage of sm. scratches ≤ 2µm in width (%)	29.08 ± 14.73	36.30 ------	27.04 ± 9.46	9.35 ± 8.01
Percentage of lg. scratches > 2µm in width (%)	52.24 ± 15.79	33.80 ------	50.62 ± 6.73	59.20 ± 21.43
Width of sm. pits ≤ 5µm	2.60 ± 0.60	3.40 ------	3.30 ± 0.50	3.80 ± 0.70
Width of lg. pits > 5µm	6.90 ± 0.50	8.60 ------	9.30 ± 1.60	11.20 ± 3.10
Width of sm. scratches ≤ 2µm	1.30 ± 0.10	1.30 ------	1.30 ± 0.10	1.30 ± 0.10
Width of lg. scratches > 2µm	3.80 ± 0.70	4.30 ------	4.20 ± 1.00	5.30 ± 1.20

Note: Values are in original (untransformed) units, reported as mean ± standard deviation.
Sample size (n) for MDH = 5, MR3 = 1, MR2 = 5, H88 = 4.

samples, consisting of first molar teeth and second molars, respectively. The 25 microwear variables include those that circumscribe the width measurements of pits and scratches, either for all features of one type (e.g. pits) on a given specimen field, or for a feature type sorted using a specific width as a sectioning point. For example, several of the scratch-related variables rely on a 2μm sectioning point, resulting in separate categories for small and large scratches. The remaining variables consist of feature frequency parameters: raw counts, and percentage of features by type or size (width) range.

Dental Microwear Data from Individual Specimens

Feature Counts and Relative Frequencies

Shown in Table 6.3 are the relative frequencies (percentages) of pits and scratches in the entire sample. Each normal specimen field (micrograph) is listed by laboratory number for both first and second molars. Also shown for each micrograph are the total feature count and unmeasured count (features present only on tilted fields). The minimum value for total feature count (6) is ascribed to specimen F-1111, an unerupted lower first molar from chalcolithic Mehrgarh, while the greatest total number of features (104) was measured on specimen M-2447T, a lower first molar from neolithic Mehrgarh (refer to Table 4-1 for specimen provenience). The raw counts for pits and scratches are listed in columns under each respective feature category. Values range from a high of 100 percent for pits on specimen F-1111, to a minimum value for pitting of 6.98 percent, with a consequent maximum value of 93.02 percent for scratches on specimen X1-4022. Arcsin transformed feature frequencies (Sokal and Rohlf 1969; Zar 1984) for the sample are listed in Table 6.4. Values, in radians, for the total and grand total feature frequencies are listed by feature type.

Table 6.3. Raw Counts and Relative Frequencies (%) of Pits and Scratches on Mandibular First and Second Molar Teeth from South Asian Archaeological Sites

Specimen	Total Features	Pits n	Pits Percentage	Scratches n	Scratches Percentage	Unmeasured Count
			Mahadaha			
U1-3412	20	5	25.00	15	75.00	18
U2-3512	32	6	18.75	26	81.25	18
V1-3612	52	16	30.77	36	69.23	9
V2-3711	28	2	7.14	26	92.86	10
W1-3812	35	11	31.43	24	68.57	33
W2-3911	24	7	29.17	17	70.83	22
X1-4022	43	3	6.98	40	93.02	23
X2-4113	31	3	9.68	28	90.32	18
Y1-4311	58	21	36.21	37	63.79	7
Y2-4412	42	12	28.57	30	71.43	28
			Neolithic Mehrgarh (MR3)			
M-2447T	104	21	20.19	83	79.81	27
N1-2512	66	11	16.67	55	83.33	21
N2-2627T	80	24	30.00	56	70.00	9
			Chalcolithic Mehrgarh (MR2)			
A1-0127N	74	22	29.73	52	70.27	38
A2-0227T	44	10	22.73	34	77.27	23
C1-0517T	51	14	27.45	37	72.55	26
C2-0617N	90	27	30.00	63	70.00	28
F-1111	6	6	100.00	0	0	0
H1-1417N	82	24	29.27	58	70.73	21
H2-1517T	68	13	19.12	55	80.88	23
I1-1627T	71	17	23.94	54	76.06	40
I2-1767T	79	17	21.52	62	78.48	37
J1-1827T	57	12	21.05	45	78.95	20
J2-1917T	71	13	18.31	58	81.69	17
			Harappa (H87/H88)			
AA1-4511	31	11	36.00	20	64.00	9
AA2-4611	44	26	59.09	18	40.91	11
BB1-4711	39	12	31.00	27	69.00	16
BB2-4811	40	6	15.00	34	85.00	9
CC1-4911	38	10	26.00	28	74.00	10
CC2-5011	43	7	16.28	36	83.72	22
EE1-5211	54	18	33.33	36	66.67	13
EE2-5311	50	18	36.00	32	64.00	11

Note: Counts (n) do not include Unmeasured Count (U.C.)

Grand Total Feature Frequencies

Table 6.5 provides a list, by specimen field, of the grand total frequency (percentage) of pits and scratches for the sample. As described in Chapter IV, the grand total feature count is the sum of measured and unmeasured features for each micrograph. Included under the column for grand total pits is the raw count of these features, as well as their relative percentage. The latter is simply the value derived from the division of the grand total pit count by the grand total feature count, multiplied by 100. Similarly, listed in the grand total scratches columns are the raw feature counts and relative feature frequencies. Again, specimen field F-1111 yielded the fewest grand total features, while the greatest number of features were recorded on specimen field M-2447T. With few exceptions, most specimen fields yielded grand total feature counts greater than 50, and more than 100 features per field were recorded on facets of several Mehrgarh molar teeth.

Feature Dimensions

Subject mean values, and their standard deviations, for pit and scratch widths are listed by specimen field in Table 6.6. Values, in micrometers (μm), consist of the average width for each feature type measured on a particular micrograph (see Chapter IV). Many of the largest pits were recorded on the Harappa specimens, with the greatest average pit width recorded on specimen field EE2-5311, a lower second molar from Harappa. Mahadaha specimens show the smallest average pit width, with the narrowest width recorded for pits on specimen field W2-3911, although some Mahadaha specimens yielded pits with substantially greater average widths. Also, many of the Mahadaha specimens yielded the narrowest scratches, with the smallest average scratch width recorded on specimen field W1-3812. Fine scratches were also recorded for some of the chalcolithic Mehrgarh specimens, while Harappa specimens generally yielded the widest average

Table 6.4. Arcsin Transformed Feature Frequencies for Mandibular First and Second Molar Teeth from South Asian Archaeological Sites

Specimen	Arcsin Pit Frequencies		Arcsin Scratch Frequencies	
	Total	Grand Total	Total	Grand Total
		Mahadaha		
U1-3412	0.52	0.44	1.05	1.13
U2-3512	0.45	0.49	1.12	1.08
V1-3612	0.59	0.57	0.98	1.00
V2-3711	0.27	0.48	1.30	1.09
W1-3812	0.60	0.56	0.98	1.01
W2-3911	0.57	0.54	1.00	1.04
X1-4022	0.27	0.38	1.30	1.19
X2-4113	0.32	0.34	1.25	1.24
Y1-4311	0.65	0.67	0.93	0.90
Y2-4412	0.56	0.55	1.01	1.02
		Neolithic Mehrgarh (MR3)		
M-2447T	0.47	0.43	1.11	1.14
N1-2512	0.42	0.38	1.15	1.19
N2-2627T	0.58	0.55	0.99	1.03
		Chalcolithic Mehrgarh (MR2)		
A1-0127N	0.58	0.51	0.99	1.06
A2-0227T	0.50	0.44	1.07	1.13
C1-0517T	0.55	0.44	1.02	1.13
C2-0617N	0.58	0.55	0.99	1.02
F-1111	1.57	1.57	0.00	0.00
H1-1417N	0.57	0.56	1.00	1.01
H2-1517T	0.45	0.42	1.12	1.15
I1-1627T	0.51	0.45	1.06	1.12
I2-1767T	0.48	0.43	1.09	1.14
J1-1827T	0.48	0.41	1.09	1.17
J2-1917T	0.44	0.44	1.13	1.13
		Harappa		
AA1-4511	0.64	0.58	0.93	0.99
AA2-4611	0.88	0.81	0.69	0.76
BB1-4711	0.59	0.53	0.98	1.04
BB2-4811	0.40	0.39	1.17	1.18
CC1-4911	0.54	0.50	1.03	1.07
CC2-5011	0.42	0.40	1.16	1.17
EE1-5211	0.62	0.63	0.96	0.95
EE2-5311	0.64	0.59	0.93	0.98

Values are in radians

Table 6-5. Grand Total Feature Counts and Percentages of Pits and Scratches for Mandibular First and Second Molar Teeth from South Asian Archaeological Sites

Specimen	GrandTotal Features	Grand Total Pits (n)	(frequency)	Grand Total Scratches (n)	(frequency)
		Mahadaha			
U1-3412	38	7	18.42	31	81.58
U2-3512	50	11	22.00	39	78.00
V1-3612	61	18	29.51	43	70.49
V2-711	38	8	21.05	30	78.95
W1-3812	68	19	27.94	49	72.06
W2-3911	46	12	26.09	34	73.91
X1-4022	66	9	13.64	57	86.36
X2-4113	49	8	16.33	41	83.67
Y1-4311	65	25	38.46	40	61.54
Y2-4414	70	19	27.14	51	72.86
		Neolithic Mehrgarh (MR3)			
M-2447T	131	23	17.56	108	82.44
N1-2512	87	12	13.79	75	86.21
N2-2627T	89	24	26.97	65	73.03
		Chalcolithic Mehrgarh (MR2)			
A1-0127N	112	27	24.11	85	75.89
A2-0227T	67	12	17.91	55	82.09
C1-0517T	77	14	18.18	63	81.82
C2-0617N	118	32	27.12	86	72.88
F-1111	6	6	100.00	0	0
H1-1417N	103	29	28.16	74	71.85
H2-1517T	91	15	16.48	76	83.52
I1-1627T	111	21	18.92	90	81.08
I2-1767T	116	20	17.24	96	82.76
J1-1827T	77	12	15.58	65	84.42
J2-1917T	88	16	18.18	72	81.82
		Harappa			
AA1-4511	40	12	30.00	28	70.00
AA2-4611	55	29	52.73	26	47.27
BB1-4711	55	14	25.45	41	74.55
BB2-4811	49	7	14.29	42	85.71
CC1-4911	48	11	22.92	37	77.08
CC-5011	65	10	15.38	55	84.62
EE1-5211	67	23	34.33	44	65.67
EE2-5311	61	19	31.15	42	68.85

Table 6.6. Mean Width of Pits and Scratches on Phase I Facets of First and Second Mandibular Molar Teeth from South Asian Archaeological Sites

Specimen	Pits (μm)	Scratches (μm)
	Mahadaha	
U1-3412	8.6 ± 7.2	3.1 ± 2.1
U2-3512	2.8 ± 2.0	2.2 ± 1.3
V1-3612	8.0 ± 4.0	3.6 ± 2.8
V2-3711	7.6 ± 0.5	3.6 ± 2.3
W1-3812	7.0 ± 3.7	1.9 ± 1.0
W2-3911	2.5 ± 1.4	3.2 ± 1.1
X1-4022	2.7 ± 1.3	2.3 ± 2.0
X2-4113	5.2 ± 2.8	3.4 ± 2.7
Y1-4311	6.7 ± 6.5*	4.3 ± 3.3
Y2-4414	4.6 ± 2.1	2.3 ± 1.2
	Neolithic Mehrgarh (MR3)	
M-2447T	5.2 ± 2.4	2.4 ± 1.9
N1-2512	6.6 ± 6.3*	3.2 ± 2.1
N2-2627T	7.5 ± 3.3	2.7 ± 1.9
	Chalcolithic Mehrgarh (MR2)	
A1-0127N	7.3 ± 2.9	3.6 ± 2.0
A2-0227T	6.2 ± 2.9	2.4 ± 1.5
C1-0517T	9.3 ± 6.6	3.5 ± 2.8
C2-0617N	5.7 ± 3.4	3.4 ± 1.8
F-1111	12.2 ± 8.7	----------
H1-1417N	5.1 ± 2.9	3.5 ± 2.6
H2-1517T	7.0 ± 3.7	2.9 ± 1.5
I1-1627T	7.9 ± 4.9	3.4 ± 2.6
I2-1767T	6.8 ± 4.2	3.1 ± 2.2
J1-1827T	5.0 ± 2.1	5.2 ± 3.7
J2-1917T	0.6 ± 10.1	4.0 ± 5.0*
	Harappa	
AA1-4511	6.7 ± 2.7	4.4 ± 2.3
AA2-4611	11.5 ± 8.3	6.4 ± 4.7
BB1-4711	12.7 ± 7.2	3.5 ± 2.3
BB2-4811	6.0 ± 2.8	4.5 ± 2.3
CC1-4911	9.2 ± 9.8*	5.2 ± 4.5
CC2-5011	5.9 ± 4.4	3.9 ± 2.2
EE1-5211	6.1 ± 3.9	5.3 ± 3.4
EE2-5311	13.1 ± 8.5	4.2 ± 2.9

* Standard deviation is large
Note: All values are mean ± standard deviation

scratches per micrograph. Group comparisons are discussed in greater detail below. Intrafield variance, represented by the standard deviations, for average pit width is high for three first molar specimens (one specimen each from neoltihic Mehrgarh, Mahadaha, and Harappa). Rather high variance for average scratch width was also observed for one of the chalcolithic Mehrgarh specimen fields (J2-1917T) produced from a second molar facet. Such a high degree of variation for mean feature dimensions is not unusual for other microwear studies of extant and extinct species (cf. Teaford and Walker 1984:Table 3). Probably the most frustrating problem associated with large amounts of variation in the samples is the lack of significant differences between group means for particular variables (further discussion below).

Pits and scratches were also sorted into specific size categories, based on the following criteria. Maas (1988, 1991) has shown that some pits may result from structural failure of enamel prisms, where they are oriented at right angles to the occlusal surface of a tooth. Furthermore, Teaford and Runestad (1992) suggest that tooth-on-tooth wear may cause small pits to form along enamel prism boundaries. The average diameter of enamel prisms in humans is reported to be 5µm (Scott and Symons 1982). In order to assess any interaction between pit size and tooth-tooth wear, a width of 5µm was chosen to partition the pits recorded on each specimen field into small and large categories.

Based on the following criteria, a 2µm sectioning point was chosen for partitioning scratches in the data sets into small and large width categories. After examining micrographs from the original chalcolithic Mehrgarh and Harappa samples, it was observed that many casting defects (bubble artifacts) have a diameter of 1µm or less (refer to Chapter IV). However, these defective micrographic fields were removed from the sample, as described previously. Therefore, the replication process itself should have no effect on the width of scratches present on the surfaces of molar facets. Solounias et al. (1988:291)

arbitrarily chose a 2μm sectioning point for categorizing small and large scratches on the teeth of fossil and extant ruminants. In fact, very thin scratches (i.e. those with a width of 2μm or less) may have a functional cause. Recent research by Ungar (1992a, 1992b) has shown that wind-borne dust in tropical rainforests of Sumatra contained clay particles with a diameter of 2μm or less. Food items covered with this type of dust, either of eolian origin or from soil contamination, were commonly eaten by macaques, langurs and orangutans, producing very narrow microscopic scratches on their incisor teeth. Opal phytoliths contained in leaves and fruits eaten by gibbons have a much larger diameter (> 2μm) than the clay particles found in low abundance in the upper levels of the forest canopy inhabited by gibbons. As a result, the consumption of such foods by gibbons produced much broader scratches on their incisors. None of the archaeological groups used in this dissertation are suspected to have consumed plant materials containing phytoliths, because these are found primarily in the leaves of monocotyledonous and dicotyledonous plants (Piperno 1988). However, large grit particles may have been introduced into the diet of the agricultural groups (Mehrgarh and Harappa) through the use of food processing implements such as grinding stones. Although data is not available for particle size produced from these implements, they are expected to have an average diameter considerably greater than 2μm (see additional discussion in Chapter VII). Consequently, it is predicted that the agricultural groups will exhibit the broadest scratches on molar facets. Although the hunting-gathering inhabitants of Mahadaha used sandstone mullers and querns for plant food processing (see Chapter III), they also would be expected to have consumed root crops which were contaminated with soil particles whose size may have been in the 2μm range. Although a 2μm sectioning point should be able to separate scratches produced by different-sized abrasives, it should be kept in mind that scratch formation on enamel surfaces is a complex process (Maas 1988) that is also a function of enamel ultrastructure.

Listed in Table 6.7 are the counts and relative proportions of small and large pits for each specimen field. Also shown are the average widths and standard deviations for each size pit recorded on the specimen fields.

With respect to features sorted into particular size categories (Tables 6.7, 6.8), two sets of values for relative frequencies are reported for each size category. These are: the proportion of features of a specific size to the total number of unsorted features of that type (e.g., pits); and the proportion of features of a specific size to the total number of scratches and pits combined (i.e., total feature count). Values from the latter category were used exclusively to produce group mean values (Tables 6.1, 6.2) for use in statistical analyses of group comparisons (discussed below).

Table 6.8 contains a list by individual specimen field of the counts and relative frequencies of small and large scratches. Fine scratches with widths between 1 and 2µm were recorded on nearly all specimen fields, although there is a considerable amount of variation in the density of fine scratches per micrograph. They were absent to barely present on some micrographs, while 20 or more fine scratches were recorded on several specimen fields. Generally, average widths of large scratches appear to cluster around the 5µm range. Few specimen fields exhibited large scratches with an average width between 5 and 10µm, and none of the specimen fields in the sample exhibited large scratches with average widths greater than 10µm. Consequently, no useful information would have been gained by partitioning the data sets using sectioning points greater than 5µm.

Small pits with average widths between 3 and 4µm were recorded on a majority of specimen fields (Table 6.7). Counts for small pits occur in a range from 1 to as high as 14 (they were absent from one of the Mahadaha specimen fields). Relative percentages of small pits ranged from as little as 2 percent to nearly 30 percent on a couple of micrographs. Average widths of large pits recorded on the specimen fields were nearly all greater than 7µm, and average widths greater than 10µm were recorded for several

Table 6.7. Counts, Relative Proportions and Mean Widths of Small and Large Pits on Mandibular First and Second Molar Teeth from South Asian Archaeological Sites

			Pits ≤ 5μm				Pits > 5μm			
Specimen	Total # Pits	Total # Feat's	n	Prop. of Total Pits	Prop. of Total Feat's	Mean Width ± std. dev.	n	Prop. of Total Pits	Prop. of Total Feat's	Mean Width ± std. dev.
					Mahadaha					
U1-3412	5	20	1	0.200	0.050	1.6 ------	4	0.800	0.200	10.4 ± 6.9
U2-3512	6	32	5	0.833	0.156	2.1 ± 0.8	1	0.167	0.031	6.6 ------
V1-3612	16	52	5	0.313	0.096	4.4 ± 0.5	11	0.688	0.212	9.6 ± 3.9
V2-3711	2	28	0	0.000	0.000	----------	2	1.000	0.071	7.6 ± 0.5
W1-3812	11	35	5	0.455	0.143	4.3 ± 0.6	6	0.545	0.171	9.3 ± 3.6
W2-3911	7	24	7	1.000	0.292	2.5 ± 1.4	0	0.000	0.000	----------
X1-4022	3	43	3	1.000	0.070	2.7 ± 1.3	0	0.000	0.000	----------
X2-4113	3	31	1	0.333	0.032	2.5 ------	2	0.667	0.065	6.6 ± 2.2
Y1-4311	21	58	14	0.667	0.241	3.6 ± 0.9	7	0.333	0.121	12.9 ± 8.4
Y2-4414	12	42	8	0.667	0.190	3.5 ± 1.0	4	0.333	0.095	7.0 ± 1.6
					Neolithic Mehrgarh (MR3)					
M-2447T	21	104	13	0.619	0.125	3.8 ± 1.1	8	0.381	0.077	7.6 ± 2.1
N1-2512	11	66	7	0.636	0.106	4.0 ± 0.8	4	0.364	0.061	11.3 ± 9.3
N2-2627T	24	80	5	0.208	0.063	3.4 ± 0.8	19	0.792	0.238	8.6 ± 2.8

Table 6.7. (Continued).

Specimen	Total # Pits	Total # Feat's	Pits ≤ 5µm: n	Pits ≤ 5µm: Prop. of Total Pits	Pits ≤ 5µm: Prop. of Total Feat's	Pits ≤ 5µm: Mean Width ± std. dev.	Pits > 5µm: n	Pits > 5µm: Prop. of Total Pits	Pits > 5µm: Prop. of Total Feat's	Pits > 5µm: Mean Width ± std. dev.
Chalcolithic Mehrgarh (MR2)										
A1-0127N	22	74	5	0.227	0.068	3.7 ± 0.9	17	0.773	0.230	8.3 ± 2.4
A2-0227T	10	44	5	0.500	0.114	3.9 ± 0.9	5	0.500	0.114	8.4 ± 2.4
C1-0517T	14	51	4	0.286	0.078	3.3 ± 1.1	10	0.714	0.196	11.7 ± 6.3
C2-0617N	27	90	12	0.444	0.133	2.7 ± 1.2	15	0.556	0.167	8.1 ± 2.5
H1-1417N	24	82	14	0.583	0.171	3.2 ± 0.8	10	0.417	0.122	7.7 ± 2.7
H2-1517T	13	68	4	0.308	0.059	3.3 ± 0.1	9	0.692	0.132	8.6 ± 3.3
I1-1627T	17	71	5	0.294	0.070	3.0 ± 1.2	12	0.706	0.169	10.0 ± 4.4
I2-1767T	17	79	8	0.471	0.101	3.6 ± 0.9	9	0.529	0.114	9.7 ± 3.7
J1-1827T	12	57	9	0.750	0.158	4.1 ± 1.0	3	0.250	0.053	7.7 ± 2.6
J2-1917T	13	71	2	0.154	0.028	3.2 ± 1.3	11	0.846	0.155	11.9 ± 10.5
Harappa										
AA1-4511	11	31	3	0.273	0.097	3.6 ± 0.5	8	0.727	0.258	7.9 ± 2.1
AA2-4611	26	44	6	0.231	0.136	3.0 ± 1.4	20	0.769	0.455	14.0 ± 7.7
BB1-4711	12	39	2	0.167	0.051	4.7 ± 0.2	10	0.833	0.256	14.3 ± 6.8
BB2-4811	6	40	3	0.500	0.075	3.6 ± 0.9	3	0.500	0.075	8.4 ± 1.0
CC1-4911	10	38	5	0.500	0.132	3.8 ± 0.8	5	0.500	0.132	14.6 ± 11.9
CC2-5011	7	43	4	0.571	0.093	3.9 ± 0.6	3	0.429	0.070	8.6 ± 6.2
EE1-5211	18	54	8	0.444	0.148	3.3 ± 1.1	10	0.556	0.185	8.2 ± 4.1
EE2-5311	18	50	1	0.056	0.020	4.7 ------	17	0.944	0.340	13.6 ± 8.4

Note: Mean Width values are in microns ± 1 standard deviation

Table 6.8. Counts, Relative Proportions and Mean Widths of Small and Large Scratches on Mandibular First and Second Molar Teeth from South Asian Archaeological Sites

			Striae ≤ 2μm				Striae > 2μm			
Specimen	Total # Striae	Total # Feat's	n	Prop. of Total Striae	Prop. of Total Feat's	Mean Width ± std. dev.	n	Prop. of Total Striae	Prop. of Total Feat's	Mean Width ± std. dev.
					Mahadaha					
U1-3412	15	20	7	0.467	0.350	1.6 ± 0.2	8	0.533	0.400	4.4 ± 2.1
U2-3512	26	32	15	0.577	0.469	1.4 ± 0.2	11	0.423	0.344	3.3 ± 1.3
V1-3612	36	52	14	0.389	0.269	1.2 ± 0.2	22	0.611	0.423	5.2 ± 2.6
V2-3711	26	28	6	0.231	0.214	1.2 ± 0.2	20	0.769	0.714	4.3 ± 2.2
W1-3812	24	35	16	0.667	0.457	1.3 ± 0.2	8	0.333	0.229	3.1 ± 1.0
W2-3911	17	24	2	0.118	0.083	1.1 -----	15	0.882	0.625	3.5 ± 0.9
X1-4022	40	43	26	0.650	0.605	1.4 ± 0.2	14	0.350	0.326	3.9 ± 2.7
X2-4113	28	31	11	0.393	0.355	1.3 ± 0.2	17	0.607	0.548	4.8 ± 2.6
Y1-4311	37	58	7	0.189	0.121	1.3 ± 0.3	30	0.811	0.517	5.0 ± 3.3
Y2-4414	30	42	14	0.467	0.333	1.2 ± 0.2	16	0.533	0.381	3.2 ± 0.9
					Neolithic Mehrgarh (MR3)					
M-2447T	83	104	49	0.590	0.471	1.3 ± 0.2	34	0.410	0.327	3.9 ± 2.2
N1-2512	55	66	16	0.291	0.242	1.3 ± 0.2	39	0.709	0.591	4.0 ± 2.1
N2-2627T	56	80	29	0.518	0.363	1.3 ± 0.2	27	0.482	0.338	4.3 ± 1.6

Table 6.8. (Continued).

Specimen	Total # Striae	Total # Feat's	Striae ≤ 2µm n	Striae ≤ 2µm Prop. of Total Striae	Striae ≤ 2µm Prop. of Total Feat's	Striae ≤ 2µm Mean Width ± std. dev.	Striae > 2µm n	Striae > 2µm Prop. of Total Striae	Striae > 2µm Prop. of Total Feat's	Striae > 2µm Mean Width ± std. dev.
Chalcolithic Mehrgarh (MR2)										
A1-0127N	52	74	10	0.192	0.135	1.3 ± 0.2	42	0.808	0.568	4.1 ± 1.8
A2-0227T	34	44	16	0.471	0.364	1.2 ± 0.2	18	0.529	0.409	3.5 ± 1.2
C1-0517T	37	51	13	0.351	0.255	1.3 ± 0.2	24	0.649	0.471	4.7 ± 2.9
C2-0617N	63	90	11	0.175	0.122	1.4 ± 0.2	52	0.825	0.578	3.8 ± 1.7
H1-1417N	58	82	15	0.259	0.183	1.4 ± 0.2	43	0.741	0.524	4.2 ± 2.6
H2-1517T	55	68	17	0.309	0.250	1.3 ± 0.2	38	0.691	0.559	3.6 ± 1.3
I1-1627T	54	71	17	0.315	0.239	1.2 ± 0.2	37	0.685	0.521	4.5 ± 2.6
I2-1767T	62	79	22	0.355	0.278	1.3 ± 0.2	40	0.645	0.506	4.1 ± 2.2
J1-1827T	45	57	9	0.200	0.158	1.2 ± 0.2	36	0.800	0.632	6.2 ± 3.5
J2-1917T	58	71	24	0.414	0.338	1.3 ± 0.2	34	0.586	0.479	5.9 ± 5.8
Harappa										
AA1-4511	20	31	1	0.050	0.032	1.1 -----	19	0.950	0.613	4.6 ± 2.2
AA2-4611	18	44	2	0.111	0.045	1.4 ± 0.3	16	0.889	0.364	7.0 ± 4.6
BB1-4711	27	39	9	0.333	0.231	1.2 ± 0.2	18	0.667	0.462	4.6 ± 2.0
BB2-4811	34	40	0	0.000	0.000	----------	34	1.000	0.850	4.5 ± 2.3
CC1-4911	28	38	4	0.143	0.105	1.4 ± 0.3	24	0.857	0.632	5.8 ± 4.6
CC2-5011	36	43	7	0.194	0.163	1.2 ± 0.2	29	0.806	0.674	4.6 ± 1.9
EE1-5211	36	54	3	0.083	0.056	1.3 ± 0.3	33	0.917	0.611	5.6 ± 3.3
EE2-5311	32	50	8	0.250	0.160	1.3 ± 0.2	24	0.750	0.480	5.1 ± 2.8

Note: Mean Width values are in microns ± 1 standard deviation

specimen fields. There is a considerable range of variation in the number of large pits recorded per micrograph, and relative frequencies also varied accordingly. As might be expected, variation in pit widths is much less in small categories. Relatively few large pits were recorded on Mahadaha specimen fields, while a considerably higher density is exhibited by specimen fields from chalcolithic Mehrgarh and Harappa. Percentages of large pits recorded on Harappa specimen fields are considerably greater than for others, which is also true for average width of all pits recorded per specimen field (discussed previously). Further discussion of group means for pit-related variables follows below.

Intergroup Comparisons of Dental Microwear

Introduction

In this section, I present group mean values and standard deviations for each microwear variable, listed by archaeological group (Tables 6.1 and 6.2), and results from univariate statistical analyses of the quantitative microwear data. In most cases, probability plots revealed that the data sets were normally distributed, or very nearly so. Transformation of the values in individual data sets frequently corrected any discrepancies (e.g. kurtosis, skewness) observed in the data.

Each of the 24 microwear variables from the sample of first and second molars was compared separately using one-way analysis of variance (ANOVA) (Tables 6.9, 6.10). Significant intergroup differences ($P < 0.05$) were found within the sample of first molars for eight variables (Table 6.9), and for 14 variables within the sample of second molars (Table 6.10). This is significantly more than would be found by chance alone for either molar type. The significant results are also presented for each variable in a series of column charts (Figures 6.1 to 6.23).

The neolithic Mehrgarh (MR3) sample was not included in the analysis of second molars, because of the small sample size ($n = 1$) which would contribute to Type II errors

Table 6.9. Analyses of Variance and Multiple Comparisons of Intergroup Differences in Dental Microwear for Mandibular First Molar Teeth from Four South Asian Archaeological Sites

Measurements	F value[a]		MDH vs. MR3	MDH vs. MR2	MDH vs. HAR	MR3 vs. MR2	MR3 vs. HAR	MR2 vs HAR
Number of features	6.08	(P<.009)	P<.05	P<.05[c]	---	---	P<.05	P<.05[c]
Grand total number of features	9.58	(P<.002)	P<.05	P<.05	---	---	P<.01	P<.01
Number of pits	1.28	---	---	---	---	---	---	---
Grand total number of pits	0.57	---	---	---	---	---	---	---
Number of scratches	8.79	(P<.002)	P<.01	---	---	---	P<.01	P<.05
Grand total number of scratches	16.22	(P<.0002)	P<.005	P<.005	---	---	P<.001	P<.005
Frequency of total pits	1.23	---	---	---	---	---	---	---
Frequency of grand total pits	1.92	---	---	---	---	---	---	---
Frequency of total scratches	1.34	---	---	---	---	---	---	---
Frequency of grand total scratches	1.90	---	---	---	---	---	---	---
Mean scratch width	3.20	(P<.06)	---	---	---	---	---	---
Mean pit width	0.66	---	---	---	---	---	---	---
Number of sm. pits ≤ 5μm in width	1.06	---	---	---	---	---	---	---
Number of lg. pits > 5μm in width	1.20	---	---	---	---	---	---	---
Number of sm. scratches ≤ 2μm in width	6.03	(P<.01)	---	---	P<.05[c]	---	P<.01	P<.05[c]
Number of lg. scratches > 2μm in width	6.09	(P<.009)	P<.05	P<.01	---	---	---	---
Frequency of sm. pits ≤ 5μm in width	0.04	---	---	---	---	---	---	---
Frequency of lg. pits > 5μm in width	1.42	---	---	---	---	---	---	---
Freq. of sm. scratches ≤ 2μm in width	4.12	(P<.03)	---	---	P<.05	(P<.025)[c]	---	---
Freq. of lg. scratches > 2μm in width	3.79	(P<.04)	---	P<.05[c]	P<.05	(P<.025)[c]	---	---
Mean width of sm. pits ≤ 5μm	0.40	---	---	---	---	---	---	---
Mean width of lg. pits > 5μm	0.60[b]	---	---	---	---	---	---	---
Mean width of sm. scratches ≤ 2μm	0.83	---	---	---	---	---	---	---
Mean width of lg. scratches > 2μm	1.54	---	---	---	---	---	---	---

a = 3, 12 degrees of freedom; b = 3, 11 degrees of freedom; c = 11 degrees of freedom (based on 3 groups).
Note: based on transformed values: square root of counts (numbers); $\log_{10}$ (common) of metric data; arcsin of frequencies (percentages).

Table 6.10. Analyses of Variance and Multiple Comparisons of Intergroup Differences in Dental Microwear for Mandibular Second Molar Teeth from Three South Asian Archaeological Sites

Measurements	F value[a]		MDH vs. MR2	MDH vs. HAR	MR2 vs. HAR
Number of features	17.09	(P<.0004)	P<.001	---	P<.025
Grand total number of features	13.40	(P<.001)	P<.005	---	P<.01
Number of pits	3.86	(P<.05)	---	---	---
Grand total number of pits	1.35	---	---	---	---
Number of scratches	13.66	(P<.001)	P<.005	---	P<.01
Grand total number of scratches	14.13	(P<.0009)	P<.005	---	P<.005
Frequency of total pits	1.19	---	---	---	---
Frequency of grand total pits	0.78	---	---	---	---
Frequency of total scratches	1.13	---	---	---	---
Frequency of grand total scratches	0.78	---	---	---	---
Mean scratch width	6.34	(P<.02)	---	P<.025	P<.05
Mean pit width	4.36	(P<.04)	---	---	---
Number of small pits ≤ 5μm in width	0.73	---	---	---	---
Number of large pits > 5μm in width	5.91	(P<.02)	P<.05	---	---
Number of sm. scratches ≤ 2μm in width	7.45	(P<.009)	---	---	P<.01
Number of lg. scratches > 2μm in width	7.56	(P<.009)	P<.01	---	---
Frequency of sm. pits ≤ 5μm in width	0.27	---	---	---	---
Frequency of lg. pits > 5μm in width	3.92	(P<.05)	---	---	---
Freq. of sm. scratches ≤ 2μm in width	4.42	(P<.04)	---	---	---
Freq. of lg. scratches > 2μm in width	0.44	---	---	---	---
Mean width of sm. pits ≤ 5μm	4.49	(P<.05)[b]	---	P<.05	---
Mean width of lg. pits > 5μm	5.82	(P<.02)[b]	---	P<.05	---
Mean width of sm. scratches ≤ 2μm	0.46[b]	---	---	---	---
Mean width of lg. scratches > 2μm	3.03	---	---	---	---

a = 2, 11 degrees of freedom; b = 2,10 degrees of freedom.
Note: based on transformed values: square root of counts (numbers); $\log_{10}$ (common) of metric data; arcsin of frequencies (percentages).

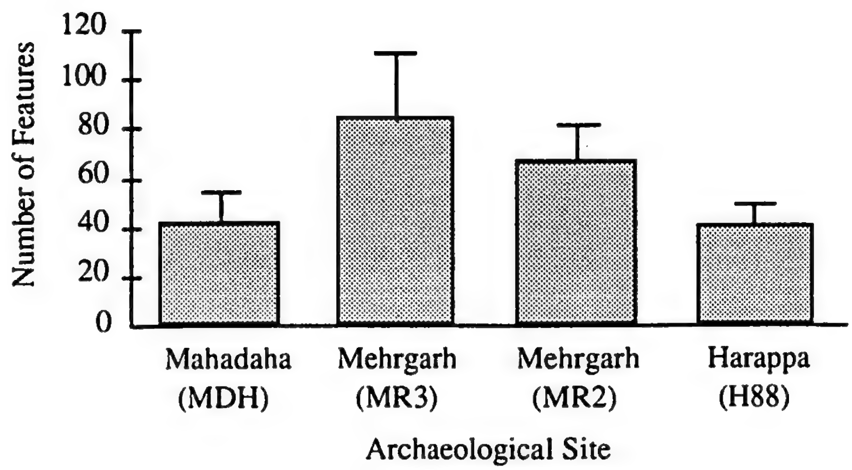


Figure 6.1. Mean Number of Features on First Molars.

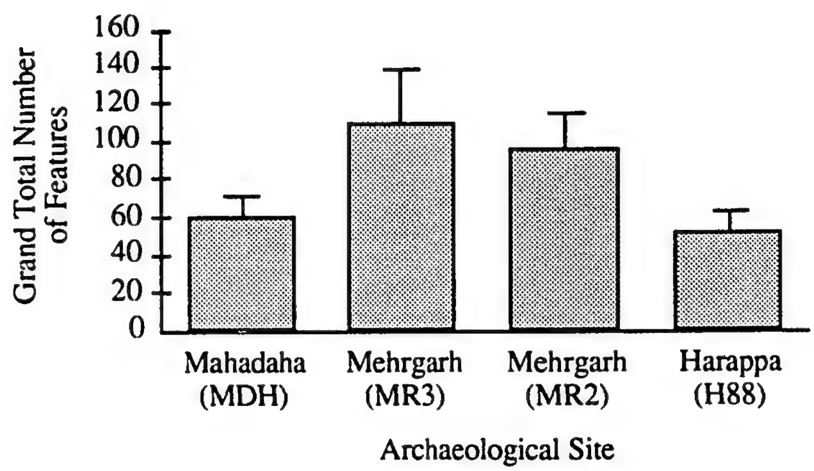


Figure 6.2. Grand Total Number of Features on First Molars.

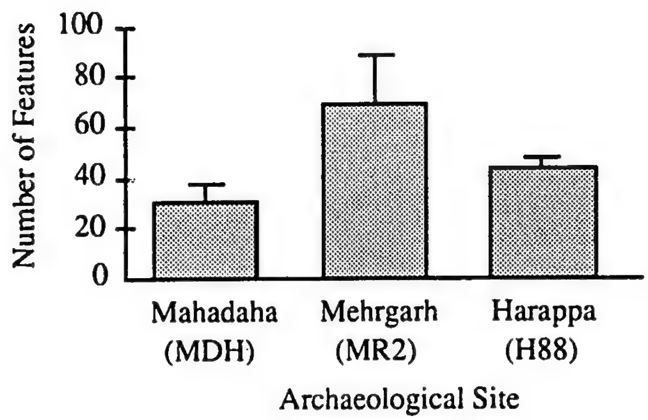


Figure 6.3. Mean Number of Features on Second Molars.

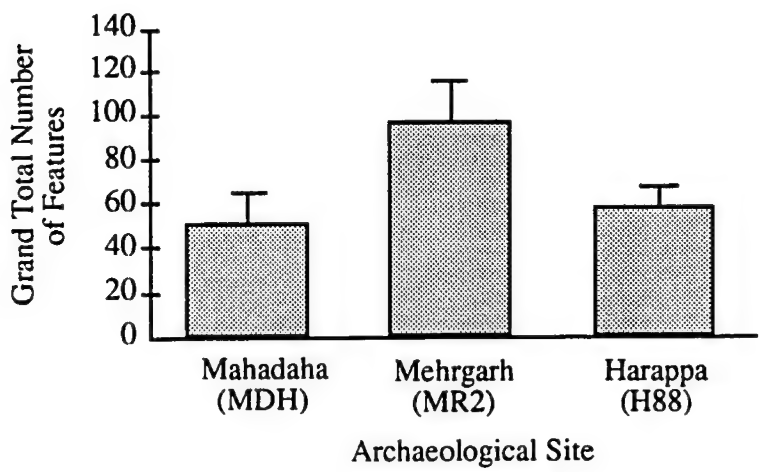


Figure 6.4. Grand Total Number of Features on Second Molars.

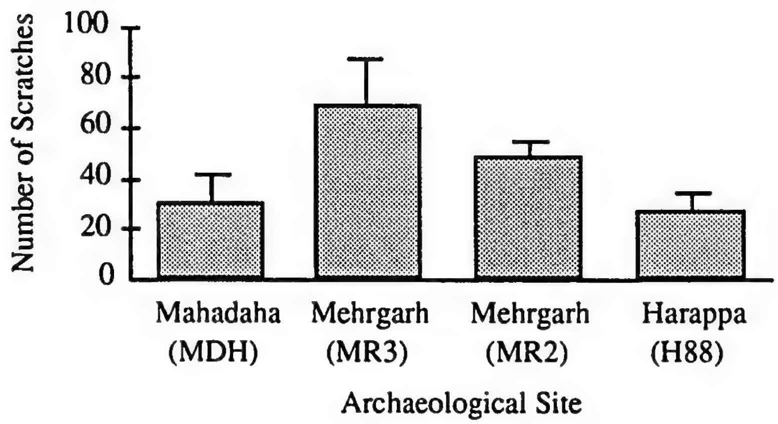


Figure 6.5. Mean Number of Scratches on First Molars.

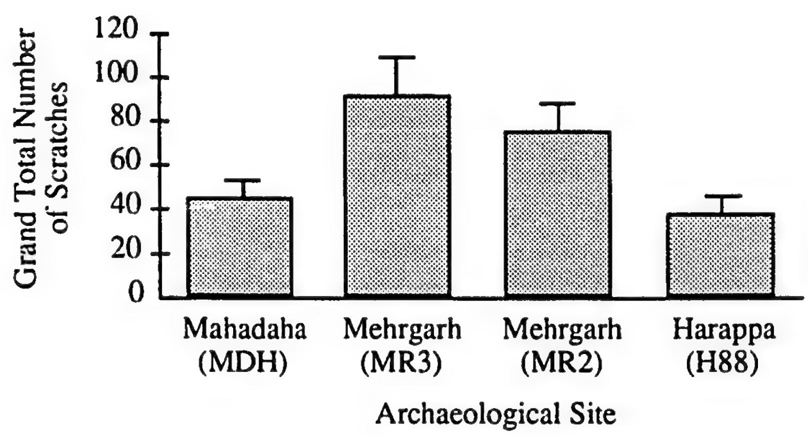


Figure 6.6. Grand Total Number of Scratches on First Molars.

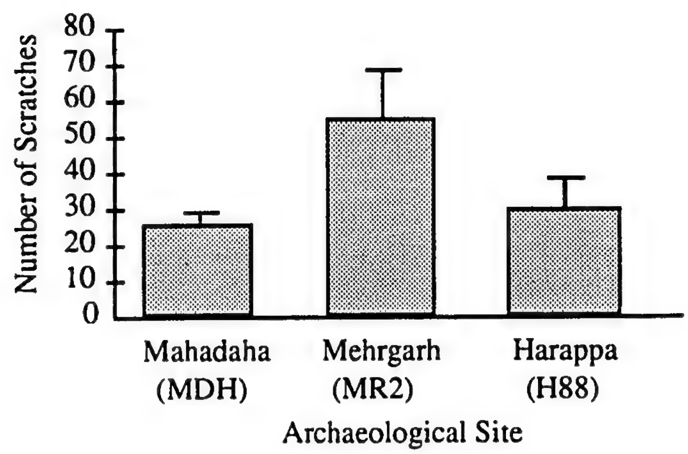


Figure 6.7. Mean Number of Scratches on Second Molars.

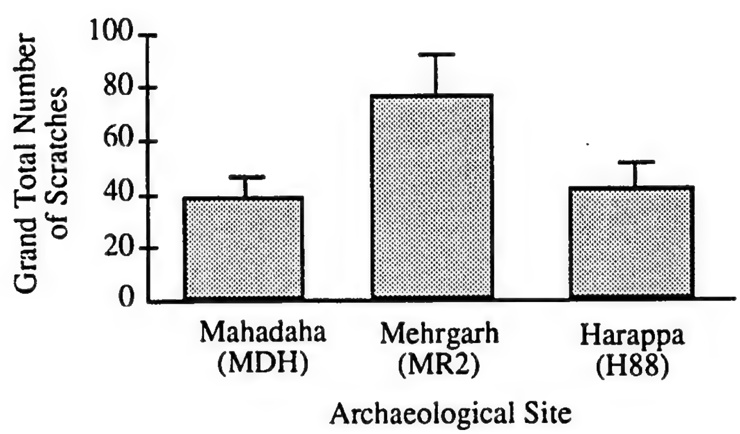


Figure 6.8. Grand Total Number of Scratches on Second Molars.

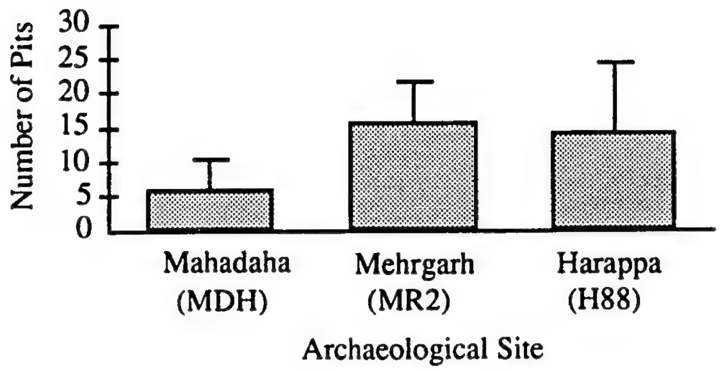


Figure 6.9. Mean Number of Pits on Second Molars.

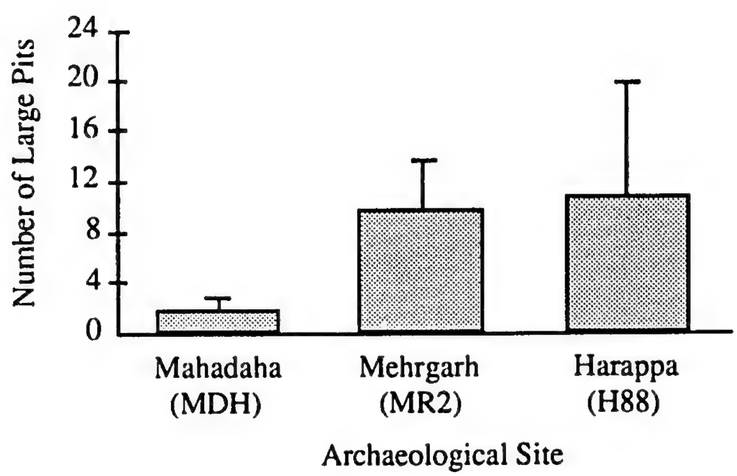


Figure 6.10. Mean Number of Large Pits on Second Molars.

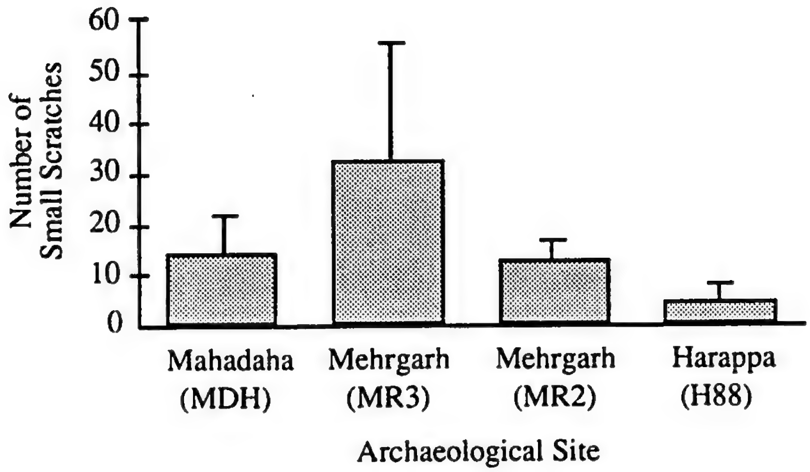


Figure 6.11. Mean Number of Small Scratches on First Molars.

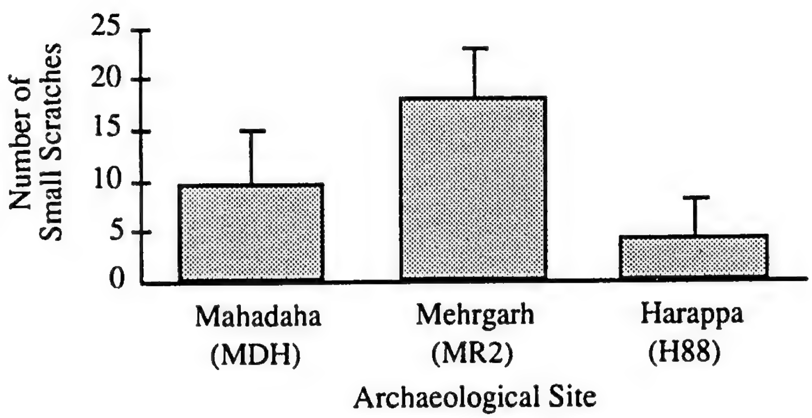


Figure 6.12. Mean Nnumber of Small Scratches on Second Molars.

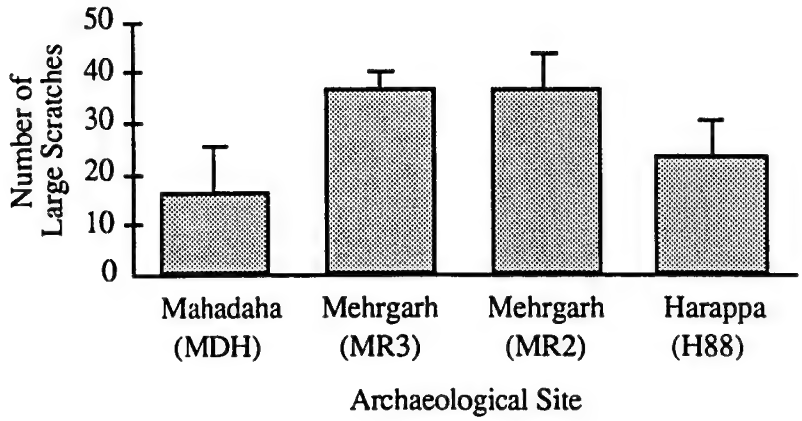


Figure 6.13. Mean Number of Large Scratches on First Molars.

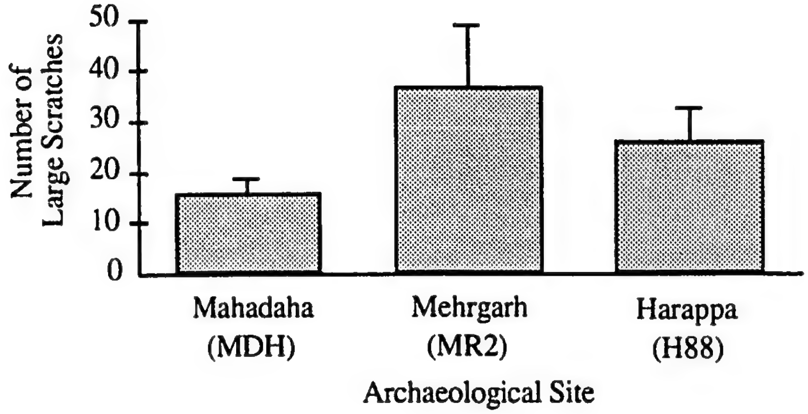


Figure 6.14. Mean Number of Large Scratches on Second Molars.

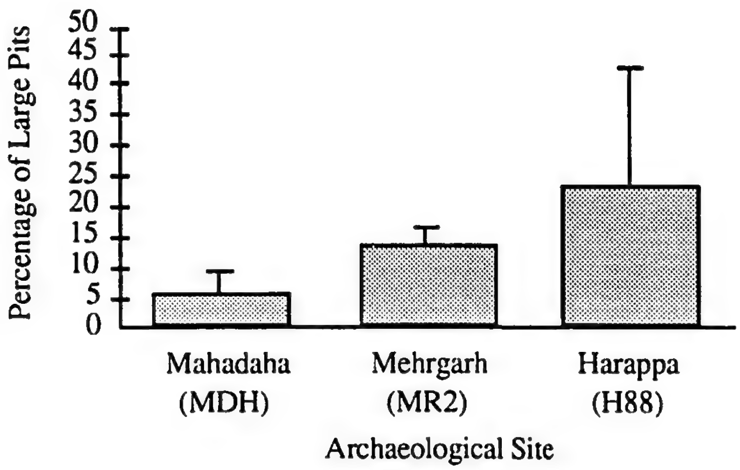


Figure 6.15. Mean Percentage of Large Pits on Second Molars.

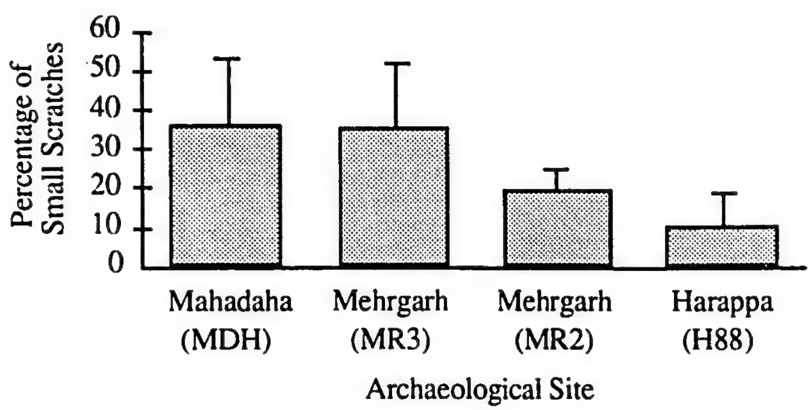


Figure 6.16. Mean Percentage of Small Scratches on First Molars.

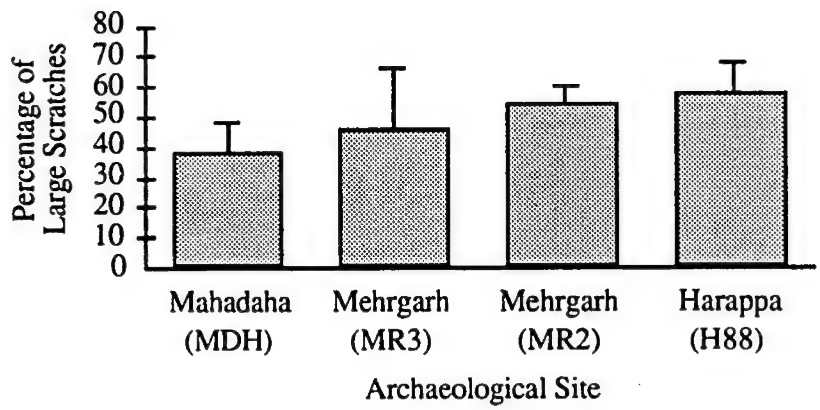


Figure 6.17. Mean Percentage of Large Scratches on First Molars.

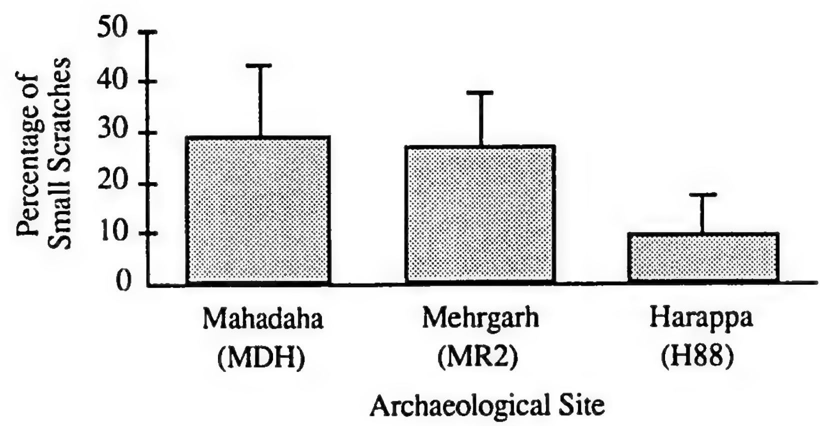


Figure 6.18. Mean Percentage of Small Scratches on Second Molars.

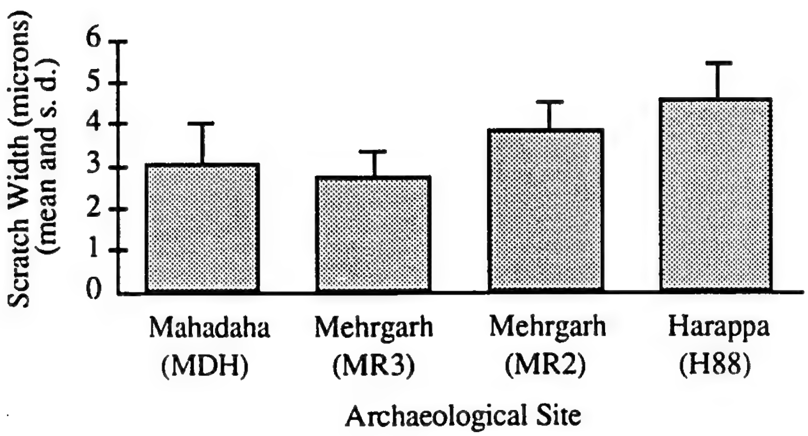


Figure 6.19. Mean Width (μm) of Scratches on First Molars.

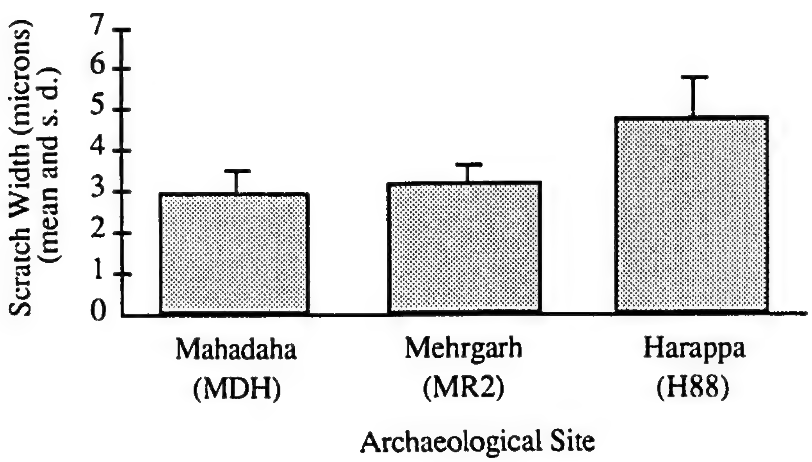


Figure 6.20. Mean Width (μm) of Scratches on Second Molars.

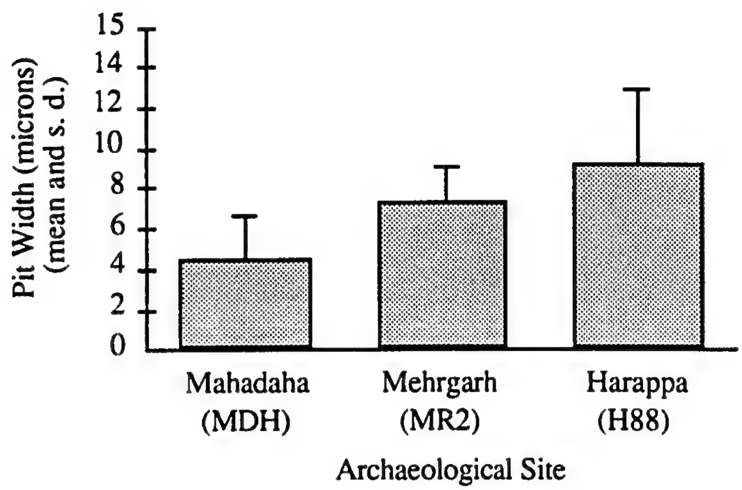


Figure 6.21. Mean Width (μm) of Pits on Second Molars.

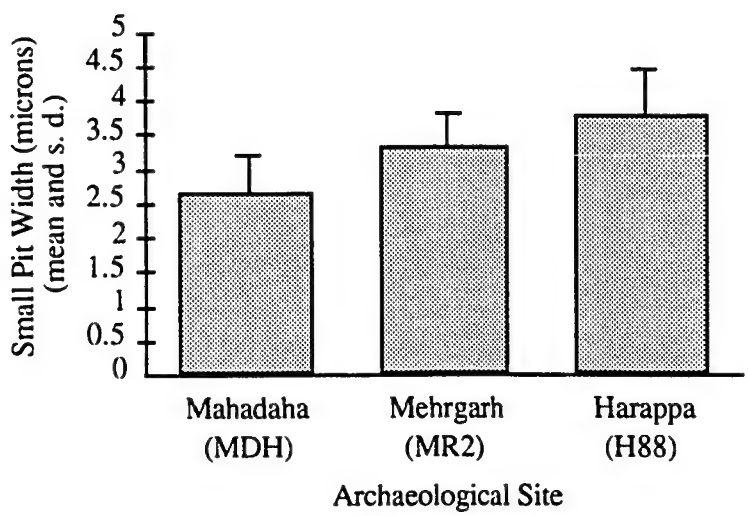


Figure 6.22. Mean Width (μm) of Small Pits on Second Molars.

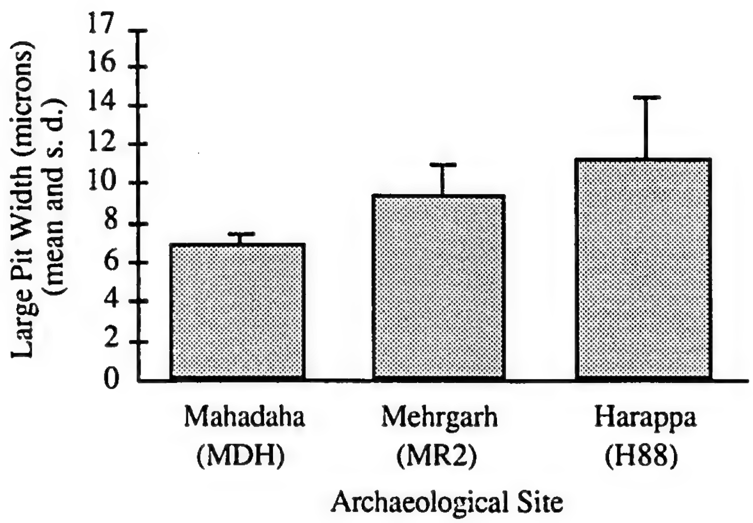


Figure 6.23. Mean Width (μm) of Large Pits on Second Molars.

(Zar 1984). Consequently, only three groups were included in the sample of second molars. A small subset of variables associated with the first molars also was tested with ANOVA for only three groups (Table 6.9), because the dissimilar size of the MR3 sample (n = 2) also contributes to Type II errors (Velleman 1988, Zar 1984).

Since ANOVA does not indicate between which groups a significant difference is located, those variables showing significant results were analyzed for intergroup differences with a Tukey-type multiple comparison test, with slight modifications for unequal sample sizes (Zar 1984:189).

Feature Counts

This category includes group mean values for total and grand total feature counts, as well as counts for pits and scratches of all sizes combined. Included are average counts for each feature type sorted by width into small and large categories (Tables 6.1, 6.2).

Variance parameters of variables are not reported for neolithic Mehrgarh (MR3) second molars (Table 6.2), because of the small sample (n = 1).

The densities of features on first molars (Table 6.1) and second molars (Table 6.2) are relatively high for the two Mehrgarh groups. For example, an average of 85 features were measured on first molars from MR3 and 67 from MR2. The average grand total feature counts recorded for these two samples were considerably higher (109 and 96, respectively). The lowest average feature count in the sample (31.4) is found in the sample of Mahadaha second molars. A significantly greater number of features ($P < 0.05$) was recorded on the neolithic Mehrgarh (MR3) first molars than on those from Mahadaha or Harappa (Figure 6.1, Table 6.9). Groups with sample sizes of three or less have been shown to limit the power of a test to distinguish significant differences between groups when they exist (Type II error), as well as limiting the control of Type I errors (Games and Howell 1976; Klockars and Sax 1986). Consequently, some of the multiple comparisons of first molars were done without including the MR3 data set (n = 2) to test whether any significant differences existed between the other three groups (Table 6.9). When three groups were compared in a separate analysis, MR2 first molars had a significantly higher incidence of features ($P < 0.05$) than the first molars from Mahadaha or Harappa. Similar results were derived from the multiple comparisons of the grand total feature count on first molars of all four groups, although at a higher level of significance ($P < 0.01$) for the comparisons between Harappa and the two Mehrgarh groups (Figure 6.2). Chalcolithic Mehrgarh has significantly more features on the second molars than either Mahadaha or Harappa ($P < 0.001$, 0.025, respectively) (Figure 6.3). Similar significant results were derived from the multiple comparisons of the grand total feature counts, although at slightly different levels of significance (Figure 6.4, Table 6.10).

Most of these group differences can be attributed to the number of scratches. Scratches are the predominant feature type recorded on either tooth, as illustrated by the

average number of pits and scratches per group, as well as by the grand totals. A significant amount of the variation represented in the feature count is explained by the variation in the average number of scratches per group. Significantly more scratches ($P < 0.01$) were recorded on MR3 than on Mahadaha first molar teeth, and first molars from the neolithic and chalcolithic Mehrgarh groups exhibited a significantly greater density of scratches ($P < 0.01$, $P < 0.05$, respectively) than those from Harappa (Figure 6.5, Table 6.9). For example, 27.75 total scratches were recorded on Harappa first molars, while 69 total scratches were recorded on first molars from MR3 (Table 6.1). Scratches on the first molars are nearly identically distributed among the groups when the grand total scratch counts are examined (Figure 6.6), although at much higher levels of significance than for the scratch counts (Table 6.9). For second molars, most of the significant differences attributed to the feature count can be explained by the significantly greater density of scratches on the MR2 teeth than on those from Mahadaha or Harappa, whether for total counts ($P < 0.005$, 0.01, respectively) (Table 6.10, Figure 6.7) or for grand total counts ($P < 0.005$) (Table 6.10, Figure 6.8).

Intergroup comparisons show that Mahadaha and Harappa have similar average pit counts for first molars (total count of 11.2 and 12.75; grand total count of 15.6 and 15, respectively), but not for second molar teeth (6 and 14.25, respectively) (Tables 6.1, 6.2). The two Mehrgarh samples also share similar pit densities for first molars (16 and 17.8, respectively), while the average pit count for chalcolithic Mehrgarh second molars is more similar to the value for Harappa second molars (15.8 and 14.25, respectively). The analysis of variance indicated significant intergroup differences ($P < 0.05$) for the total pit count on second molars, but not for the grand total number of pits (Table 6.10). Although considerably fewer pits were recorded on the Mahadaha teeth (Table 6.2, Figure 6.9) than on the second molars from Mehrgarh or Harappa, significant differences were not distinguished by the multiple comparisons (Table 6.10).

When the average numbers of small and large pits are examined, a clear pattern is not readily apparent for either molar type from the majority of the groups (Tables 6.1, 6.2). However, Mahadaha first molars exhibit equal numbers of small and large pits (5.6), and the second molars exhibit the fewest number of large pits (1.8), compared to the other groups. Significant intergroup differences were not found for counts of either small or large pits on first molars. However, significant differences were found for the density of large pits on second molars. The number of large pits on MR2 second molars was significantly greater ($P < 0.05$) than that on Mahadaha teeth (Figure 6.10). Although the density of large pits is even greater on Harappa molars, the difference is not significant because of the high amount of variance in the data set (Table 6.2).

With regard to the number of small and large scratches, both tooth types from Harappa exhibit fewer small scratches than those from other sites (Figure 6.11). Molar teeth from both Mehrgarh sites exhibit the highest average number of either size scratch, except for the small scratch count for MR2 first molars. A significant difference exists between the neolithic and bronze age groups ($P < 0.01$) based on the number of small scratches on the first molars. Comparison of only three groups (see earlier discussion) revealed significant differences ($P < 0.05$) between Harappa and the Mahadaha and MR2 groups for the number of small scratches on first molars (Table 6.9). When the density of fine and coarse scratches on second molars was compared between three groups, significant intergroup differences were indicated for the small scratch count ($P < 0.009$) (Table 6.10). The number of small scratches is significantly greater ($P < 0.01$) on second molars from MR2 than from Harappa, and Mahadaha teeth exhibit an intermediate value (Figure 6.12).

The multiple comparisons revealed that Mahadaha had significantly fewer large scratches on first molars than the neolithic or chalcolithic Mehrgarh groups ($P < 0.05$, $P < 0.01$, respectively) (Figure 6.13). In addition, MR2 second molars exhibited a

significantly greater number of large scratches ($P < 0.01$) than Mahadaha, and Harappa occupies an intermediate position between these two groups (Table 6.10, Figure 6.14).

Feature Frequencies

As described for feature counts, all groups uniformly exhibit a higher relative frequency of scratches than pits. First molar teeth from neolithic Mehrgarh (MR3) had the highest incidence of scratches compared to the other groups, whether computed for total (81.57%) or grand total percentages (84.33%) (Table 6.1), and correspondingly the lowest average incidence of pits. For second molars, Mahadaha had the highest total percentage of scratches and the lowest percentage of pits compared to the other groups. The relative scratch frequency for first molars from the MR2 group becomes the second highest (79.01%) when the grand total percentages are taken into account. Harappa first and second molars exhibit identical incidences of pitting (total of 31.5%, grand total of 28%), values that are slightly higher than other groups. However, multiple comparisons of the group means produced no significant differences (Table 6.9).

For the second molars, Mahadaha and MR2 are not significantly different from each other for total or grand total frequencies of pits or scratches (Tables 6.2 and 6.10). Although Harappa second molars exhibited the highest average pit frequency, whether for total (31.59%) or grand total (28.39%), these parameters did not prove significantly different from the other two groups, probably due to the large degree of variation within the Harappa sample. Also, it is interesting that the grand total feature frequencies are within three to four percentage points of the corresponding total frequencies for any of the groups (Table 6.2). This fact has important methodological implications, which will be discussed in Chapter VII.

Although significant differences are not present, intergroup comparisons generally reveal that for total percent of either pits or scratches Mahadaha and chalcolithic Mehrgarh

(MR2) first molars are most similar, while MR3 and Harappa are most similar for second molars. The former relationship does not hold as well for grand total feature frequencies, because the incidence of pits decreases while scratches increase in frequency for MR2 first molars.

Since the average frequencies of small and large features reported in Tables 6.1 and 6.2 are computed in terms of total feature counts, the values for each group provide additional information to that derived from the average count of a particular feature (discussed above). The percent of small pits on first molars is nearly identical for all groups (approximately 11%). First molars from MR3 have the smallest percentage of large pits (6.9%), Harappa shows the largest value for percent of large pits (20.78%), while Mahadaha and MR2 exhibit similar values for percent of large pits (14.2% and 15.4%, respectively). For second molars, MR2 and Harappa have similar percentages of small pits (8.7% and 8.1%, respectively), while MR3 and Harappa share similar (and the highest) percentages of large pits (23.8% and 23.5%, respectively). Mahadaha second molars exhibit the highest average frequency of small pits (13.4%), and the lowest average frequency of large pits (5.44%). The F-test indicated that significant group differences were present for the frequency of large pits on second molars ($P < 0.05$) (Table 6.10), and a trend is apparent for an increasing density of large pits for the more culturally complex groups (Figure 6.15, Table 6.2). However, this and other intergroup differences for frequencies of small and large pits were not significantly different on the Tukey test for either molar type.

The Mahadaha first molars had a significantly higher mean percentage of small scratches (36.04%) than the Harappa teeth ($P < 0.05$) (Figure 6.16, Table 6.9). Although the MR3 group shares nearly identical mean values and standard deviations with Mahadaha, this group was not determined to be significantly different from Harappa, because of its small sample size (Games and Howell 1976). The greatest percentages of

large scratches are found on MR2 and Harappa first molars (54.32% and 57.95%, respectively). Harappa first molars have fewer average small scratches (10.6%) and more large scratches compared to first molars from the other groups, but only the difference with Mahadaha is significant. Approximately equal proportions of small and large scratches (average of 37%) are found on Mahadaha first molar teeth. The MR2 first molars were intermediate to the other groups for the mean percentage of small scratches (Figure 6.16). With regard to the frequency of large scratches, the Mahadaha first molars exhibited significantly fewer ($P < 0.05$) than the Harappa molars, and fewer than those from the chalcolithic group ($P < 0.05$) when the multiple comparison analysis was run with only three groups (Figure 6.17).

Approximately equal proportions of small and large scratches are also found on MR3 second molar teeth (Table 6.2). In addition, Mahadaha and MR2 second molars share similar values for percent small scratches (29.08% and 27.04%, respectively) and large scratches (52.24% and 50.62%, respectively). Significant intergroup differences ($P < 0.04$) were indicated for the frequency of small scratches, but not large scratches, on the second molars (Table 6.10). As with first molar teeth, Harappa second molars exhibit a considerably lower frequency of small scratches (9.35%) and more large scratches (59.2%), on average, than the two other groups (Figure 6.18). However, significant intergroup differences for the percentage of small scratches were not produced by the multiple comparison analysis, probably due to the high variances in the data sets.

Feature Widths

Group mean values of feature widths were calculated for combined features and for features sorted by size (Tables 6.1 and 6.2). In general, there is little intragroup variation between the mean scratch widths of first and second molars. With the exception of Harappa teeth, scratches on first molars from all other groups are slightly wider than on

second molars, although the difference is negligible for MR3. For example, the average width of scratches recorded on MR2 first molars is 3.9µm, but 3.2µm on the second molars. When examined by group, the widest scratches are found on first and second molars from Harappa, with an average scratch width of 4.6µm for first molars and 4.7µm for second molars. The narrowest scratches were recorded on first and second molars of MR3 individuals (2.8µm and 2.7µm, respectively), but Mahadaha scratches were only slightly wider. For first molars, these intergroup differences in scratch width were not significant (Figure 6.19). However, the average width of scratches recorded on Harappa second molars is significantly greater than on Mahadaha or chalcolithic Mehrgarh teeth (0.025, 0.05, respectively) (Figure 6.20).

As with scratch dimensions, average pit widths on either molar type from Harappa are considerably greater than those from other groups. The second largest average pit widths were recorded on first and second molar teeth of chalcolithic Mehrgarh (MR2) individuals. The smallest pits were recorded on neolithic Mehrgarh (MR3) first molars (5.9µm) and Mahadaha second molars (4.5µm). For first molars, none of these group differences were significant. For second molars, these intergroup differences were shown to be significant on the analysis of variance test, but not when specific group comparisons were analyzed with the Tukey test (Figure 6.21).

When pits are partitioned into small and large categories, very little intergroup variation is apparent for the width of small pits with the exception of Mahadaha second molar teeth (2.6µm). However, the largest pits in the small pit category were recorded on Harappa molar teeth (3.8µm), while Mahadaha molars generally showed the smallest average pit width. In general, first molars from all groups had wider small pits than did second molars. Again, the Harappa teeth exhibited the greatest average width for pits in the large pit category (approximately 11µm for either molar type). Mahadaha second molars had the narrowest large pits (6.9µm), but the first molars had the second largest average pit

width (10.5μm) for the large pit category. In general, few intergroup differences are apparent between first molars for either pit size category, especially considering the amount of variation (standard deviations) existing around each group mean. As a result, none of the differences were significant. This is not the case for the second molars, especially those from Mahadaha and Harappa. Multiple comparisons of width measurements for pits sorted by size revealed significant intergroup differences. Average width of both small and large pits on Harappa second molars were significantly larger than those on Mahadaha teeth. In fact, nearly identical trends are apparent for both pit categories, with a progressive increase in pit size between the mesolithic, chalcolithic, and bronze age groups (Figures 6.22 and 6.23).

With respect to scratches partitioned by width, all groups have identical values for the average width of small scratches (1.3μm) for first and second molar teeth, except for a negligibly larger width on Mahadaha first molars. Harappa molars of both types exhibited the greatest average widths for large scratches. The narrowest large scratches on first molars were recorded for MR3, but those on second molars were recorded for Mahadaha. For first molars, mesolithic and neolithic groups had narrower scratches, on average, than the bronze age group.

Summary

In summary, the results from the multiple comparisons of the first molar teeth indicate a generally higher density of large scratches in the bronze age group, and a greater density of small scratches in the mesolithic hunting-gathering group and the neolithic group. This can be viewed as a trend or gradient in which finer microwear features are common to hunting-gathering and incipient agricultural lifeways, whereas coarser features are typical of sedentary agricultural lifeways. Also, there appears to be a greater density of features of all sizes, especially scratches, among neolithic and chalcolithic groups.

The sample of second molar teeth showed significant intergroup differences associated with the density of microwear features. The density of features, especially scratches of all sizes, is highest for the chalcolithic group and lowest for the mesolithic group, as with the first molar teeth. More pits of all sizes are concentrated on the second molars of the chalcolithic and bronze age groups, and the latter group has a considerably higher density of large pits than the others. Density measures for fine scratches show that the bronze age group has generally coarser microwear than the less culturally complex groups. This is also confirmed by the density measures for large scratches, in which case the mesolithic group has the fewest while the two agricultural groups have many more of these large features. Furthermore, the bronze age group has uniformly broader scratches than the less culturally complex groups. Interestingly, a trend for pit size is present, with generally smaller pits among the mesolithic groups increasing to larger pits in the chalcolithic group. The largest pits are exhibited by the later bronze age group. As is true for first molars, this can be expressed as a trend in which finer microwear features are common to hunting-gathering lifeways, whereas coarser features are typical of sedentary agricultural lifeways. Intermediate-size features are typical of the chalcolithic group, which is intermediate to the other groups in terms of cultural complexity and food processing technology (e.g., archaeological assemblage, diet, culinary practices).

Within Groups Sex Differences for Dental Microwear

Introduction

Few, if any, dental microwear studies of prehistoric groups have attempted intragroup comparisons for sex differences. Therefore, the following investigation of sex differences in dental microwear for the South Asian archaeological groups can be considered a pilot-type trial study. For this study, the samples containing individuals of both sexes (chalcolithic Mehrgarh and Harappa) were partitioned into separate categories,

based on the individuals for whom skeletal elements were identifiable for sex (see Table 3-1, Chapter III). This resulted in subdivided Harappa and chalcolithic Mehrgarh (MR2) samples that each consisted of equal numbers (n = 2) of male and female individuals. Intragroup comparisons for sex differences were analyzed with the Student's t-test. It must be emphasized that because of the very small sample sizes involved, these analyses of sex differences should be considered exploratory, but valuable, because: (1) other dental microwear analyses of prehistoric samples have not explored sex differences; (2) an analysis of Harappan sex differences for molar microwear may provide further insight on the documented sex differences for status and dental health at Harappa; (3) such an analysis applied to Mehrgarh molars may also prove insightful with regard to the documented sexual dimorphism and sex-based status differences at Mehrgarh.

The same variables used for intergroup comparisons (Tables 6.9 and 6.10) were used to test for intragroup sex differences. The values associated with specific variables are listed by individual specimen in Tables 6.3 to 6.8.

Harappa

Listed in Table 6.11 are mean values and standard deviations for significant ($P < 0.05$) microwear variables and other selected variables for male and female individuals at Harappa. Most of the significant variables (6) are associated with the second molar teeth, while only a single significant variable is associated with the first molars. Illustrated in Figure 6.24 are pit counts partitioned by sex for both first and second molars. The second molars of females exhibit significantly more pits of all sizes than those of males ($P < 0.05$). Slightly greater pit densities are also present on first molars of females than males, but the difference is not significant (Table 6.11). These differences between the sexes at Harappa are also reflected in the total pit frequencies for both molar types (Figure 6.25), the grand total pit counts and frequencies for first molars, as well as the

Table 6.11. Harappa Sex Differences for Selected Microwear Variables on Mandibular First and Second Molar Teeth

Variables	Female	Male
Number of pits, M1	14.50 ± 4.95	11.00 ± 1.41
Number of pits, M2*	22.00 ± 5.66	6.50 ± 0.71
Grand total number of pits, M2	24.00 ± 7.07	8.50 ± 2.12
Pit width, M1 (µm)	6.40 ± 0.50	11.00 ± 2.50
Pit width, M2 (µm)*	12.30 ± 1.20	6.00 -------
Number of large pits, M1	9.00 ± 1.41	7.50 ± 3.54
Number of large pits, M2*	18.50 ± 2.12	3.00 -------
Percentage of large pits, M1	22.15 ± 5.16	19.40 ± 8.77
Percentage of large pits, M2*	39.75 ± 8.13	7.25 ± 0.35
Width of large pits, M1 (µm)*	8.10 ± 0.20	14.50 ± 0.20
Width of large pits, M2 (µm)*	13.80 ± 0.30	8.50 ± 0.20
Percentage of pits, M1	34.67 ± 1.89	28.50 ± 3.54
Percentage of pits, M2	47.55 ± 16.33	15.64 ± 0.91
Grand total percentage of pits, M1	32.16 ± 3.06	24.19 ± 1.79
Grand total percentage of scratches, M1	67.84 ± 3.06	75.81 ± 1.79

Values are in original (untransformed) units, reported as mean ± standard deviation.
* Significant at $P < 0.05$

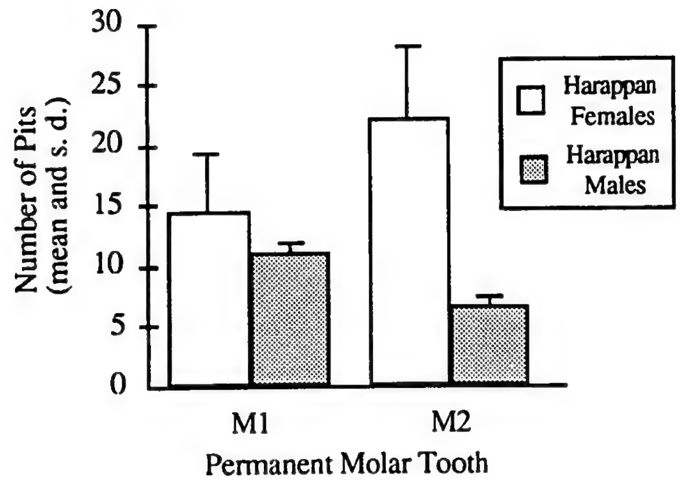


Figure 6.24. Sex Differences for Mean Number of Pits on Harappa First and Second Molars.

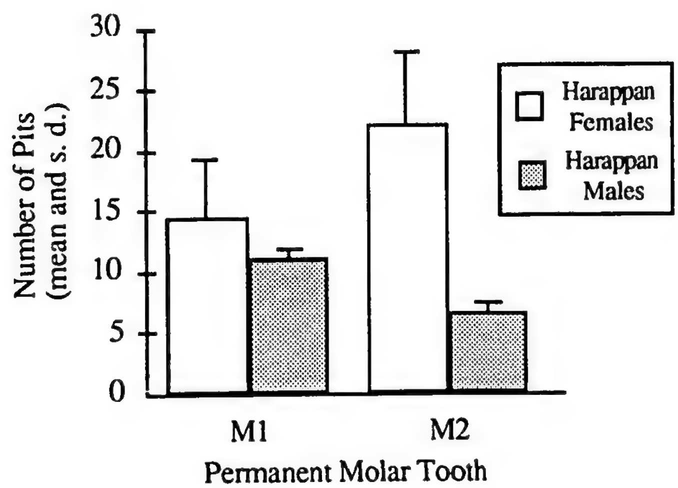


Figure 6.25. Sex Differences for Mean Percentage of Pits on Harappa First and Second Molars.

corresponding grand total frequency for scratches on first molars (Table 6.11), although none of the differences exhibited by these parameters were significant.

When pit size was compared, females were found to exhibit significantly larger pits ($P < 0.05$) on second molars than the males in the sample (Table 6.11). However, the reverse of this trend was exhibited for first molars. In this case, average pit widths for first molars of males were larger than those of female individuals, although the difference was not significant (Figure 6.26).

Comparisons of sex differences for small and large pits revealed that the average counts, frequencies, and widths of large pits on the molar teeth were considerably different between the sexes. As with average pit width, the width of large pits on female second molars was significantly larger ($P < 0.05$) than on the second teeth of males, whereas a reverse trend was present for significantly greater widths of large pits ($P < 0.05$) on the first molars of males than females (Figure 6.27, Table 6.11). Only slight sex differences were recorded for the number and frequency of large pits on the first molars, but significantly greater densities of large pits ($P < 0.05$) were recorded for second molars of females than males (Figures 6.28, 6.29, Table 6.11).

In summary, significant sexual dimorphism exists within the small Harappa sample for several parameters of dental microwear, primarily those associated with the density and size of pits. The second molar teeth in the sample appear to be a key tooth, because most of the significant differences occur for this tooth. In general, a significantly greater pit density was recorded on molars of females than males. In addition, larger pits are present on the second molars of females, but the trend is reversed for first molars.

Chalcolithic Mehrgarh

None of the results of the t-tests comparing sex differences at MR2 were significant. However, mean values for several of the variables suggest possible differences

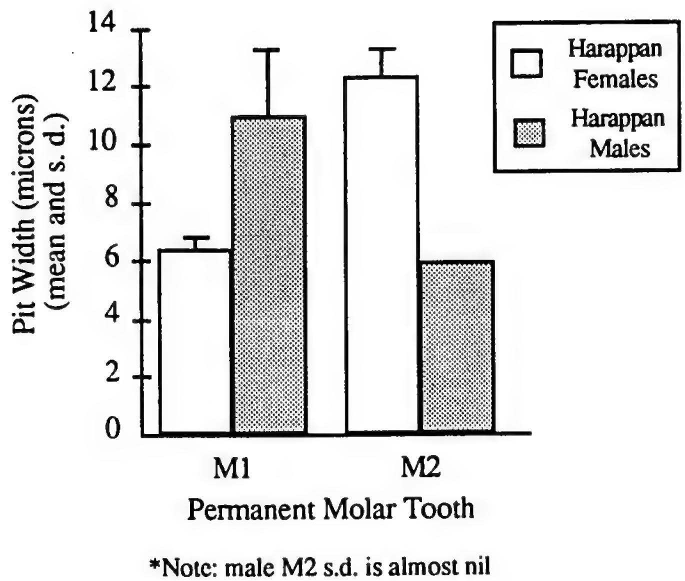


Figure 6.26. Sex Differences for Mean Width (μm) of Pits on Harappa First and Second Molars.

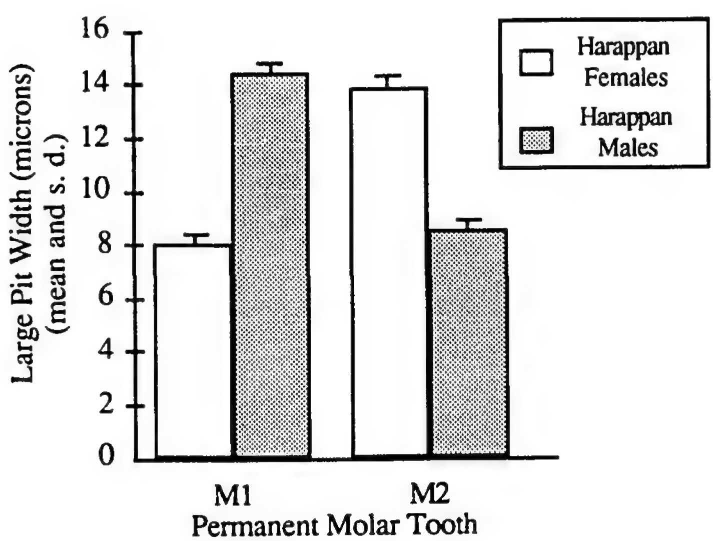


Figure 6.27. Sex Differences for Mean Width (μm) of Large Pits on Harappa First and Second Molars.

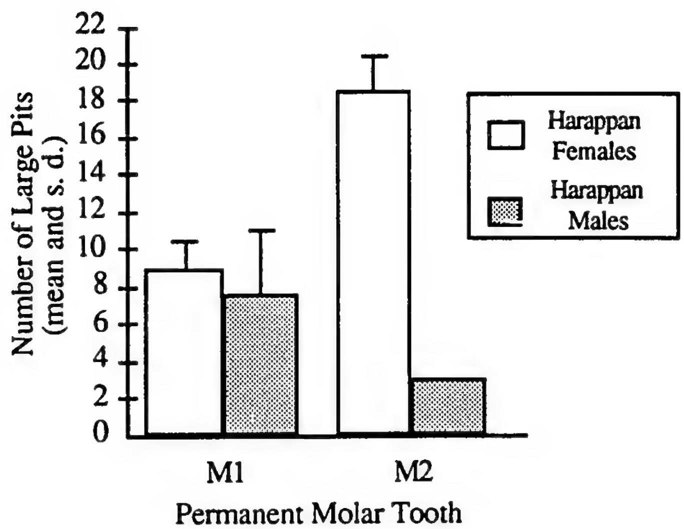


Figure 6.28. Sex Differences for Mean Number of Large Pits on Harappa First and Second Molars.

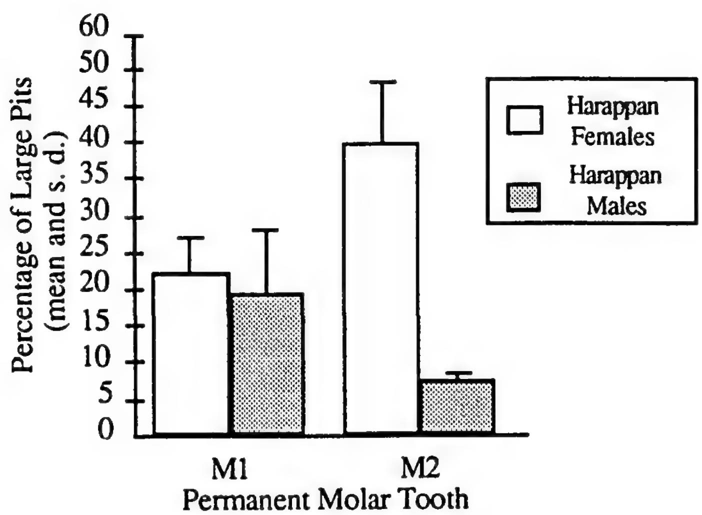


Figure 6.29. Sex Differences for Mean Percentage of Large Pits on Harappa First and Second Molars.

second molars.between the sexes (Table 6.12). For example, the average width of large pits on first molar teeth of females was larger than on those of males. Likewise, the average size of large scratches on female first molars was slightly greater than for males. Compared to males, females had a lower average frequency of pitting (grand total percentage), and higher average frequency of scratching, on their first molars (Table 6.12). However,a more interesting and somewhat confusing picture exists when the raw pit counts for first molars are compared to second molars. For first molars, fewer pits were recorded for females than males, as with the grand total frequencies, while considerably more pits were recorded on the second molars of females than on those of males. Consequently, opposite trends for sex differences are associated with the particular molar types. Because of the small sample sizes and consequent lack of significant differences, it is possible that these results represent no more than the action of serendipity.

In summary, average values for the majority of variables were not different between the sexes. Although suggestive sex differences are present for a few microwear parameters, none of these differences were significant when analyzed with the t-test.

Table 6.12. Chalcolithic Mehrgarh Sex Differences for Selected Microwear Variables

Variables	Female	Male
Number of pits, M1	15.50 ± 2.12	23.00 ± 1.41
Number of pits, M2	21.50 ± 6.36	11.50 ± 2.12
Grand total percentage of pits, M1	18.55 ± 0.52	26.13 ± 2.86
Grand total percentage of scratches, M1	81.45 ± 0.52	73.87 ± 2.86
Percentage of small scratches, M1	24.70 ± 1.13	15.90 ± 3.39
Width of large pits, M1 (μm)	10.90 ± 1.20	8.00 ± 0.40
Width of large scratches, M1 (μm)	4.60 ± 0.20	4.20 ± 0.10

Values are in original (untransformed) units, reported as mean ± standard deviation

Intergroup Comparisons of Dental Attrition

Introduction

In the following sections, I discuss the quantitative analyses of the dental attrition, scored by the degree of wear, for first and second molar teeth in the largersample. Since the rate of macroscopic wear has been shown to be correlated with the rate of dental microwear (Teaford and Oyen 1989a, 1989b), it seems worthwhile to quantitatively compare the severity of dental wear between the archaeological groups. Therefore, the former comparisons were accomplished by examination of descriptive statistics and through one-way ANOVA and multiple comparisons performed on the wear scores of molar teeth in the sample. Multivariate analyses (principal components and discriminant functions) were undertaken to investigate the contributions of dental wear and microwear variables to the explained variance between the groups.

Included in the sample were equal numbers (n = 5) of first and second molars from Mahadaha and chalcolithic Mehrgarh, for a total of ten molar specimens from each of these groups. The combined Harappa sample (H87 and H88) for first and second molars consisted of one right and three left antimeres from the H87 sample and four right antimeres from the H88 sample, for a total sample size of sixteen (n = 8 for each molar type). Mehrgarh specimen F (MR2-36A) and Harappa specimens K1/K2 (H87-60-46a-32) were not included in the sample because of the young ages of the individuals and/or the relatively unworn status of the teeth (see Chapter IV).

Specimen Data and Descriptive Statistics

The Molnar scores for degree of wear and Scott total scores for individual molar teeth are listed in Table 6.13, together with information on sex and age at death of the

Table 6.13. Individual Wear Scores for Molar Specimens Used in Group Comparisons and Multivariate Analyses

Specimen Label	Molar Type	Provenience	Age/Sex	Molnar Score Degree	Scott Score Total
		Chalcolithic Mehrgarh (MR2)			
A1	LM1	MR2-42	Adult / Male	4	21
A2	LM2	MR2-42	Adult / Male	2	10
C1	RM1	MR2-60	16 yr / Female	3	12
C2	RM2	MR2-60	16 yr / Female	3	8
H1	RM1	MR2-34	Y. Adult / Male	2	9
H2	RM2	MR2-34	Y. Adult / Male	2	7
I1	LM1	MR2-45	Adult / Female	3	18
I2	LM2	MR2-45	Adult / Female	3	12
J1	RM1	MR2-46	11-12 yr / unknown	3	15
J2	RM2	MR2-46	11-12 yr / unknown	2	6
		Harappa (H87/H88)			
B1	LM1	H87-37	11 yr / unknown	3	14
B2	LM2	H87-37	11 yr / unknown	2	5
D1	LM1	H87-60	20 yr / Female	4	19
D2	LM2	H87-60	20 yr / Female	2	10
E1	LM1	H87-71	22 yr / Female	3	17
E2	LM2	H87-71	22 yr / Female	2	13
G1	RM1	H87-85	30 yr / Female	4	19
G2	RM2	H87-85	30 yr / Female	2	10
AA1	RM1	H87-145	29 yr / Female	3	20
AA2	RM2	H87-145	29 yr / Female	3	16
BB1	RM1	H88-191	19 yr / Male	4	19
BB2	RM2	H88-191	19 yr / Male	2	7
CC1	RM1	H88-200	18 yr / Male	4	18
CC2	RM2	H88-200	18 yr / Male	2	9
EE1	RM1	H88-197	25 yr / Female	4	18
EE2	RM2	H88-197	25 yr / Female	3	16

Table 6.13. (Continued).

Specimen Label	Molar Type	Provenience	Age/Sex	Molnar Score Degree	Scott Score Total
		Mahadaha			
U1	RM1	MDH-2	17-20 yr / Male	5	27
U2	RM2	MDH-2	17-20 yr / Male	5	22
V1	RM1	MDH-11	18-23 yr / Male	4	20
V2	RM2	MDH-11	18-23 yr / Male	3	17
W1	LM1	MDH-1	18-21 yr / Male	3	15
W2	LM2	MDH-1	18-21 yr / Male	2	11
X1	RM1	MDH-15	20-25 yr / Male	4	22
X2	RM2	MDH-15	20-25 yr / Male	3	16
Y1	RM1	MDH-26	19-21 yr / Male	5	23
Y2	RM2	MDH-26	19-21 yr / Male	2	16

individual from whom the teeth were derived for the reduced data set used in these analyses. As described in Chapter IV, biological age (i.e., age at death) was determined previously using standard osteological methods and techniques. The relative closeness in age of death for the majority of individuals from the three samples means that age was essentially controlled for in the comparison, and attritional differences must be due to individual variation in mastication, diet, food preparation, or the use of the teeth in non-masticatory behavior (Molnar 1972).

The attrition observed on the occlusal surfaces of the Harappan and chalcolithic Mehrgarh molars is generally moderate, with the buccal cusps of most of the specimens exhibiting much more dentine exposure than the lingual cusps. The occlusal surface form of the more severely worn first molars of Harappans is completely concave, while the Mehrgarh first molars exhibit a partially concave to completely concave form of wear (Molnar 1971). Shown in Table 6.14 are mean values and standard deviations of Scott and Molnar wear scores for first and second molars from the combined Harappa sample, as well as those from Mehrgarh and Mahadaha. With few exceptions, the degree of wear is greatest for Mahadaha molars, intermediate for Harappa, and lowest for Mehrgarh molars. As previously discussed in Chapter V, both the degree and form of macroscopic tooth wear exhibited by residents of Harappa and chalcolithic Mehrgarh resemble that of other prehistoric agricultural populations whose diets generally consist of soft, sticky, high carbohydrate foods prepared from processed grains. By contrast, the lingual cusps of Mahadaha molars retain some of their original height in the more moderately worn teeth. The occlusal surfaces of more severely worn teeth possess a partially concave to flat form, and most frequently tilt in a plane toward the buccal surface. Unlike the molars from the two agricultural groups, the degree of attrition of the Mahadaha molars is similar to other hunter-gatherer populations from North America, Europe and the Near East, in which the

Table 6.14. Means and Standard Deviations of Wear Scores for First and Second Molars from Three Archaeological Groups

Group	Molnar Score	Scott Score
Mahadaha		
M1	4.20 ± 0.84	21.40 ± 4.39
M2	3.00 ± 1.22	16.40 ± 3.91
Mehrgarh (MR2)		
M1	3.00 ± 0.71	15.00 ± 4.74
M2	2.40 ± 0.55	8.60 ± 2.41
Harappa (H87/H88)		
M1	3.63 ± 0.52	18.00 ± 1.85
M2	2.25 ± 0.46	10.75 ± 3.99

wear plane tilts buccally at a shallow angle. This pattern of attrition is consistent with a subsistence diet at Mahadaha of rough textured, fibrous, and abrasive foods.

Multiple Comparison Analyses

As acomplished with the dental microwear variables, one-way ANOVA's were performed on wear scores of first and second molars for all individuals in the sample, including the combined Harappa sample (Table 6.15). Significant differences were indicated for all but one of the variables, Molnar scores for second molars. This indicates that significant differences in mean wear score exist within the sample of archaeological groups. Tukey-type multiple comparisons were performed on the three significant variables to determine between which groups the significant differences exist. Significant group differences were found for two of the variables, first and second molar Scott scores (Table 6.15). The degree of macroscopic wear of first and second molars from Mahadaha (MDH) is significantly greater than molars from Mehrgarh (MR2) ($p < 0.05$ and .025, respectively). In addition, Mahadaha first molars are significantly more worn than those from Harappa ($p < 0.05$). Although the mean Scott scores for Harappa first and second molars are greater than those from Mehrgarh (Table 6.14), the variability within the samples is high and the differences are not significant (Table 6.15).

Multivariate Analyses of Wear and Microwear

Introduction

Multivariate analytical methods, such as principal components or discriminant function analyses, provide information on the contribution to the variability of a data set by particular variables or groups of variables. In addition, multivariate methods can produce a few functions or vectors, from a large number of variables, which efficiently partition the variability between several groups. Principal components analysis and discriminant

Table 6.15. Analyses of Variance and Multiple Comparisons of Intergroup Differences in Dental Attrition, Based on Molnar and Scott Wear Scores for First and Second Molar Teeth

Measurements	F value[a]	MDH vs. MR2	MDH vs. HAR	MR2 vs. HAR
Scott scores				
M1	3.62 (P<.05)	P<.05	---	---
M2	6.04 (P<.01)	P<.025	P<.05	---
Molnar scores				
M1	3.29 (P<.06)	---	---	---
M2	2.02	---	---	---

a = 2, 16 degrees of freedom

function analysis each test a multivariate set of data in slightly different ways. A principal component analysis facilitates the description of multivariate data in a concise fashion with fewer 'dimensions,' by extracting one or more principal components or orthogonal vectors from the entire variance in the data (Shennan 1988; Velleman 1988). Discriminant function analysis is most frequently employed to determine to what degree "it is possible to separate two or more groups of individuals, given measurements for these individuals on several variables" (Manly 1986:86). Discriminant analysis is also distinct from principal components analysis in that it is useful for testing hypotheses regarding group separation (Shennan 1988), but it can also serve as an exploratory technique. In other words, discriminant analysis takes as a basic assumption the fact that the archaeological groups can be distinguished from each other based on some criterion (e.g., artifact typologies), and then tests this assumption against the set of variables for tooth wear. Sets of significant wear variables will have the ability to "maximize the differences" between the different archaeological groups in multivariate space (Shennan 1988:287).

Of interest was how measures of wear, principally Scott scores, performed in comparison with microwear parameters in their ability to account for the shared variability within a multivariate data set. Molnar scores were not used in the multivariate analyses, because the group means were not significantly different from each other. For the Harappa sample, only those specimens for which both wear scores and microwear parameters were available were used in the multivariate analyses. This reduced the multivariate data set for Harappa by one-half (n = 4 individuals).

Principal Components Analysis

A reduced data set for the first molars was used for the principal components analysis, consisting of Scott scores and the six significant microwear variables from the multiple comparisons, with the exception of the two significant grand total variables (Table 6.9). Principal components were computed from the correlation matrix, which was produced by first standardizing each x-variable, and then computing the crossproduct matrix (Velleman 1988). Rotation of the principal axes after the components were extracted (Norusis 1985) was not attempted, due to statistical software limitations. Therefore, the unrotated factor matrix is reported here (Table 6.16) and used to interpret the variability in the data set.

Illustrated in Table 6.16 are eigenvalues for the three principal components and the proportion of variance explained by each component. Although by convention, only eigenvalues greater than one are used in subsequent analyses, the eigenvalue for the third principal component is included because it accounts for 10.0% of the total variance. Also illustrated is a 7 x 3 matrix of eigenvector coordinate values listed for each of the seven variables for the first three principal components. The unrotated factor matrix coefficients are also listed for the same variables as computed for the first three principal components. These values are equal to the product of a particular eigenvector coordinate value and the square root of the corresponding eigenvalue.

Two components were extracted with eigenvalues greater than one, while the third principal component has an eigenvalue that is smaller than one. Illustrated in Table 6.16 are the eigenvalues, eigenvector (orthogonal vector) coordinate values, non-rotated factor matrix coefficients, and percentage of total variance explained by the first three principal components.

Table 6.16. Component Loadings, Coefficients, Eigenvalues, and Percentage of Total Variance Explained, Based on Dental Wear and Microwear Parameters for First Molar Teeth

	Principal Component		
Parameters	One	Two	Three
	Eigenvector Coordinate Values		
Scott score	-0.274	0.220	0.931
Number of features	0.463	-0.269	0.162
Number of scratches	0.427	-0.346	0.217
Number of small scratches	-0.058	-0.613	0.120
Number of large scratches	0.521	-0.017	0.176
Percentage of small scratches	-0.324	-0.480	0.086
Percentage of large scratches	0.386	0.390	0.081
	Unrotated Factor Matrix Coefficients		
Scott score	-0.519	0.352	0.778
Number of features	0.877	-0.431	0.135
Number of scratches	0.809	-0.555	0.181
Number of small scratches	-0.110	-0.982	0.101
Number of large scratches	0.988	-0.027	0.147
Percentage of small scratches	-0.614	-0.769	0.072
Percentage of large scratches	0.731	0.625	0.068
Eigenvalue	3.593	2.566	0.697
Variance Proportion (%)	51.3%	36.7%	10.0%
Total Explained Variance		98.0%	

The first principal component exhibits an eigenvalue of 3.593 and accounts for slightly more than one-half (51.3%) of the explained (shared) variance in the sample. High scores along the first principal component represent individuals from the sample whose molar teeth exhibit a high density of coarse features, particularly scratches with large widths.

The second principal component possesses an eigenvalue of 2.566 and accounts for 36.7% of the total variance in the sample. The highest value along this principal component, whether for the eigenvector coordinates or for the factor matrix coefficients, is attributed to the number of scratches with narrow widths. The percentages of small and large scratches possess the second highest scores. This component features lower scores for features not sorted by size, for wear score, and for the number of large striae. Therefore, the density of small scratches contributes most of the explained variation accounted for by this second component.

The third principal component exhibits an eigenvalue of 0.697, accounting for 10.0% of the total variance. Macroscopic dental wear reflects the sole high score along this component. Therefore, wear score contributes little to the explained variance within the reduced data set. Taken as a whole, these first three principal components account for 98% of the explained variance. Since the first two components alone capture 88% of the total original variance, there is no net loss of information when these two components are used to interpret the variability in the data set, in lieu of the original seven variables (Harris and Bailit 1988).

In summary, the principal components analysis demonstrates that two orthogonal vectors of variance are able to explain much of the variation in molar wear and microwear differences for first molar teeth. Most of the explained variability in the reduced data set is accounted for by the density of large scratches. The remainder of explained variability is

accounted for by the density of fine scratches, and to a smaller extent by the relative frequencies of small and large scratches.

Discriminant Function Analysis

The statistical operations for the discriminant function analysis were performed by Dr. Brian Hemphill using an MS-DOS format computer and SYSTAT statistical software (Wilkinson 1988). As with the principal components analysis, a reduced data set of seven univariately significant variables was used for first molar teeth. For the second molars, a reduced data set included Scott scores and twelve of the dental microwear variables shown to be significant by the ANOVA's (Table 6.10). However, the initial univariate test conducted in the discriminant function routine showed only nine of these 13 variables to be univariately significant across the three groups. Also, the multivariate analysis could not be completed because of problems of colinearity and missing data for two of the variables (small pit width, large pit width) (see Table 6.7). A second run of the discriminant function analysis was attempted on a more reduced data set, consisting of eight of the nine significant variables from the first run and excluding the variables with missing cases. Although the problems of colinearity and missing data were solved, and despite the fact that all eight of the variables were significant across the three groups, lack of statistical significance for either of the discriminant functions indicated that the results of the second discriminant analysis perform poorly. Finally, a third discriminant analysis was undertaken on a second molar data set, consisting of six of the seven variables used to separate groups for the first molar. A seventh variable, percentage of large pits, was substituted for the percentage of large scratches because it was thought that data on pit densities might provide better separation of the groups for second molars. This third run of the discriminant analysis was successful, with univariate significance across the groups for six of the variables, and near significance ($P = 0.052$) for the percentage of large pits.

Results from the subsequent routines of the discriminant analyses for the second and first molar data sets are described below.

Calculation of multivariate differences for first molar teeth indicate significant separation of the groups for Wilks' Lambda ($F = 2.691$, $P < 0.06$) and for Pillai trace ($F = 2.816$, $P < 0.04$), but not for the Hotelling-Lawley trace statistic ($F = 2.459$, $P < 0.10$). Similar results were obtained for the second molar sample, although at higher levels of significance. The non-significance of the Hotelling-Lawley trace simply reflects the sensitivity of this statistical test to small samples (Hemphill, personal communication 1992). The resulting significance levels for the first two of these statistics indicate that there is relatively little chance that observed differences between the South Asian archaeological groups occur serendipitously.

The latent roots for the series of discriminant functions were tested for significance with Bartlett's chi-square statistic. Discriminant functions with significant latent (residual) roots were retained for further analysis. For the first molars, the chi-square statistic for roots 1 through 2 is 24.988 ($P = 0.03$), and for second molars this statistic is 26.328 ($P = 0.02$) for roots 1 through 2. Thus, significant multivariate separation was obtained for both of the tooth samples on the first discriminant function. The second discriminant function was not significant for either the first or second molar sets, but with the small sample sizes involved, the degree of separation found along the second function is still important. As a further indication of the performance of the discriminant functions, the canonical correlation coefficients were examined. The canonical correlation provides "a measure of association which summarizes the degree of relatedness between the groups and the discriminant function" (Klecka 1980:36). The fact that the canonical correlations are very high for both discriminant functions for the two tooth samples indicates that the groups are very different on the variables analyzed. Also, both the first and second

discriminant functions appear meaningful and provide useful information for explaining the differences between the groups (Klecka 1980).

The subsequent procedures used in the discriminant function analyses follow those outlined by Hemphill (1991:159) and Klecka (1980). They include the derivation of canonical loadings and scaled vector coefficients by function for each variable. The matrix of canonical loadings illustrates the contribution of each variable to the separation of the groups by the discriminant functions. Then, the canonical loadings were multiplied by individual values for each dental wear and microwear variable. Sums of the resulting products were separately calculated across all variables for each function. Finally, centroid scores for each canonical variable were derived by averaging the individual scores for each function by sample. Two-dimensional ordination of the centroid scores was undertaken to illustrate the relationships (relative distances) between the archaeological groups.

Table 6.17 lists the canonical loadings of the first two discriminant functions for the first molar teeth. Discriminant function one separates the archaeological groups on the bases of microwear feature density, particularly the number of large scratches, and on the amount of macroscopic wear. As illustrated in Table 6.17, high negative canonical loadings are obtained for the following parameters: number of features, number of scratches, and number of large scratches. By contrast, the Scott score receives the highest positive loading on this function. The high negative scores along this discriminant function represent individuals from the sample of groups whose molar teeth exhibit few microwear features, particularly large scratches (see Table 6.1). By contrast, the high positive scores along function one represent individuals with high Scott scores (see Table 6.14).

The groups are separated by discriminant function two on the basis of scratch densities, primarily the smaller scratches, on the first molars. The canonical loadings are highest for the number of small scratches and the percentage of small scratches, which have very high negative scores, and for the percentage of large scratches, which has a very high

Table 6.17. Canonical Loadings from Discriminant Function Analysis of Dental Wear and Microwear Parameters for First Molar Teeth

	Discriminant Function	
Parameters	One	Two
Number of large scratches	-0.436	0.101
Number of scratches	-0.406	-0.303
Number of features	-0.377	-0.212
Scott score	0.301	-0.062
Percentage of large scratches	-0.291	0.616
Percentage of small scratches	0.164	-0.634
Number of small scratches	-0.064	-0.727

positive score. The high scores along this discriminant function represent individuals whose molar teeth exhibit few fine scratches, on the one hand, and a relatively high proportion of wide scratches on the other hand. This indicates that function two serves to distinguish between the density of scratches of different shape.

These results are illustrated in Figure 6.30 where discriminant function scores for each individual in the three groups are ordinated in two-dimensional space. Group clusters of points are relatively discreet, although values for chalcolithic Mehrgarh (MR2) show a wider spread, with the value of one of the cases in proximity to the Mahadaha point cluster. Two-dimensional ordination of group centroid scores is illustrated in Figure 6.31. Distinct and nearly equidistant separation between the three groups is present, especially for factor one. Based on the group scores for function one, Harappa and Mahadaha are separated by their Scott scores and by microwear feature densities, particularly for large scratches. Mehrgarh is marked by an intermediate score on function one. By contrast, Mahadaha is marked by a relatively small negative score on function two, Harappa is marked by a more intermediate score, while Mehrgarh is separated from these two groups by a high positive score along this function. These group scores along function two indicate that Mehrgarh and Mahadaha are distinct from each other based on the densities of small scratches. Examination of group mean values of microwear variables for the first molars (Table 6.1) partially supports these conclusions from function two. For example, Mahadaha first molars have nearly equal proportions of small and large scratches, while first molars from Mehrgarh and Harappa exhibit much lower percentages of small scratches and relatively high percentages of large scratches. Group averages for the variables that separate the groups along function one are reflected by the differences in some, but not all, of these variables. This separation is best represented by Scott scores, where Mahadaha stands alone from the other two groups due to the much higher rate of wear on the first molars (Table 6.14). The number of large scratches, which is low for Mahadaha and higher for

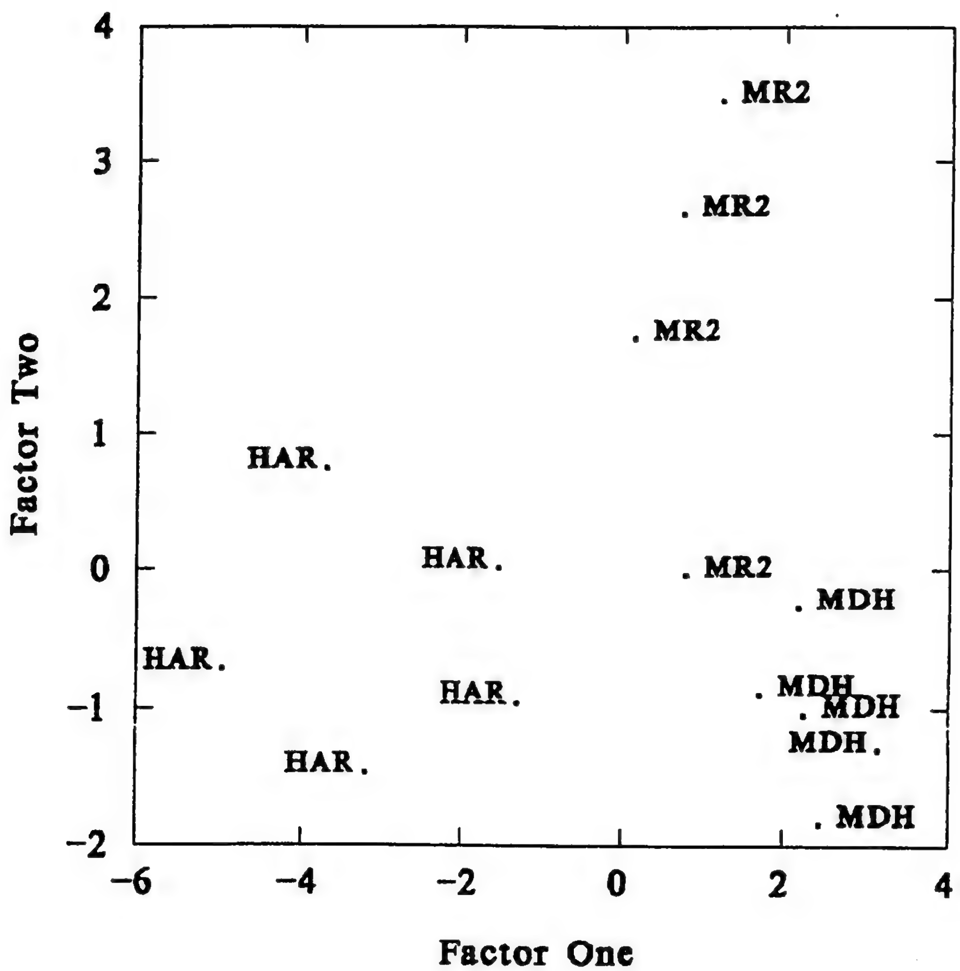


Figure 6.30. Two-Dimensional Ordination of Individual Discriminant Function Scores for First Molars of Three Archaeological Groups.

both Mehrgarh and Harappa, also partially reflects the separation indicated along function one.

Listed in Table 6.18 are the canonical loadings of the first two discriminant functions for the second molar teeth. As with the first molars, discriminant function one separates the archaeological groups on the bases of microwear feature density, particularly the number of large scratches, and the amount of macroscopic wear. High positive canonical loadings are obtained for the following parameters: number of features, number of scratches, and the number of large scratches. In contrast, the Scott score produced the highest negative canonical loading, although the absolute value is smaller than the scores obtained for the above microwear parameters. The groups that receive high positive loadings along the first discriminant function are marked by relatively high counts for the number of large scratches, scratches of all sizes, and total features, accompanied by low Scott scores. By contrast, groups that receive negative loadings along the first component are marked by relatively high Scott scores, and relatively low counts for the number of large scratches, scratches of all sizes, and total features. Two-dimensional ordination of the individual and group centroid discriminant function scores (Figures 6.32 and 6.33, respectively) illustrate these results. Distinct and nearly equidistant separation is present between the three groups along factor one (Figure 6.33). Examination of the average values of these microwear variables (Table 6.2) and Scott scores (Table 6.14) for the three groups reveals that they do provide the separation indicated by function one. Mahadaha and Mehrgarh second molars show an inverse relationship for Scott scores and the three microwear parameters, while Harappa second molars yield intermediate mean values.

The second discriminant function for the second molars draws a distinction between the number of small scratches and the percentage of small scratches, which receive very high positive loadings, and the percentage of large pits, which receives a relatively high negative loading. Consequently, groups that have a high positive score along the second

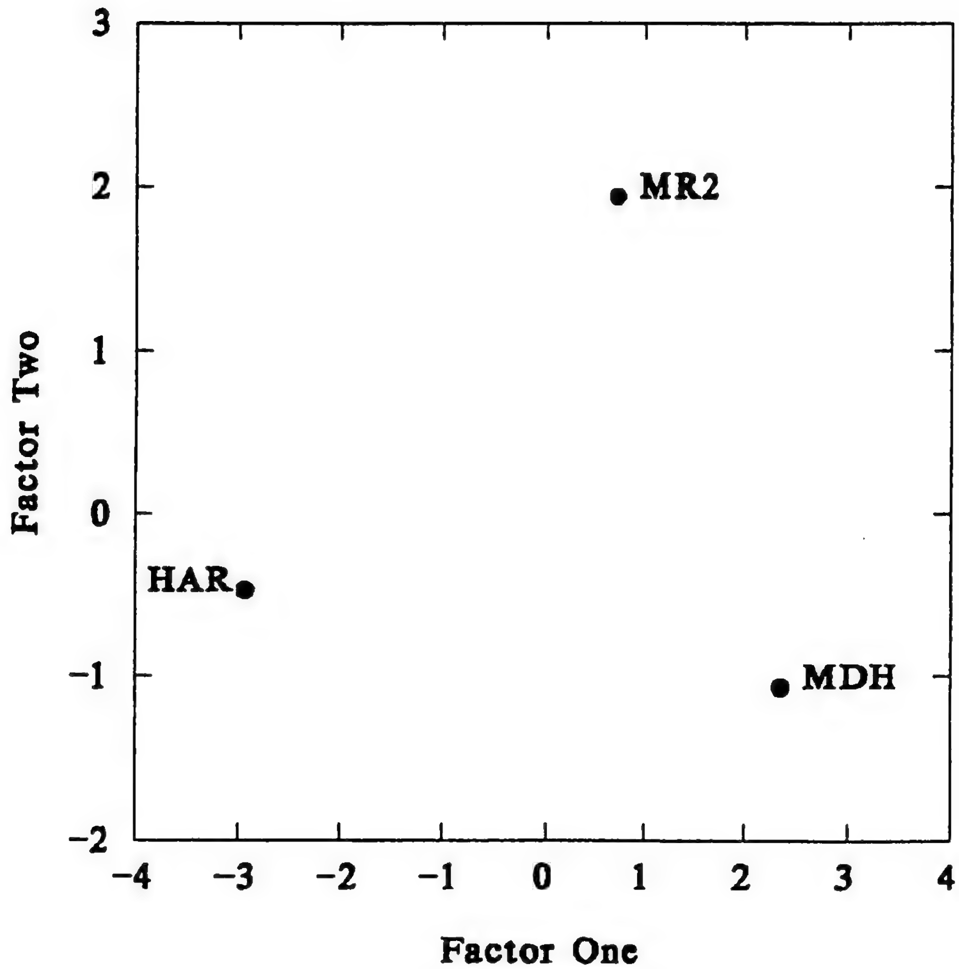


Figure 6.31. Two-Dimensional Ordination of Group Centroid Discriminant Function Scores for First Molars of Three Archaeological Groups.

Table 6.18. Canonical Loadings from Discriminant Function Analysis of Dental Wear and Microwear Parameters for Second Molar Teeth

	Discriminant Function	
Parameters	One	Two
Number of features	0.639	0.075
Number of scratches	0.551	0.291
Number of large scratches	0.424	-0.077
Scott score	-0.363	0.087
Number of small scratches	0.257	0.632
Percentage of large pits	0.179	-0.469
Percentage of small scratches	0.002	0.612

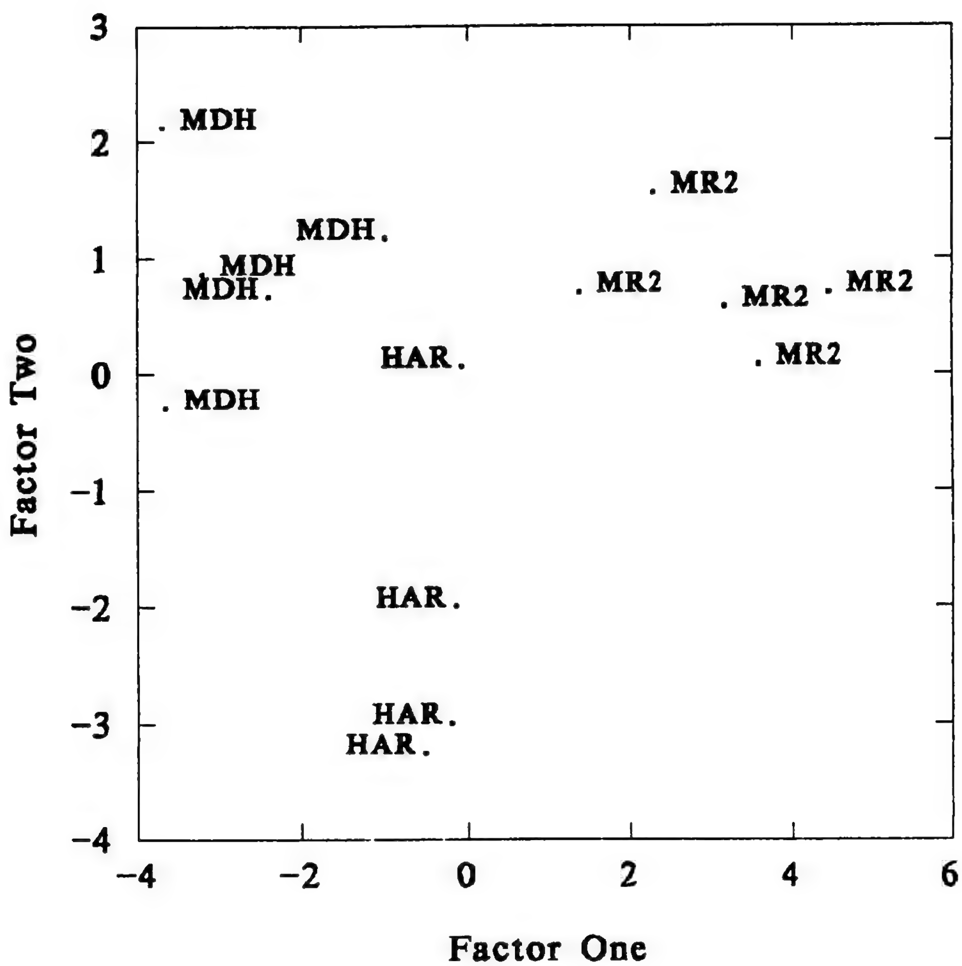


Figure 6.32. Two-Dimensional Ordination of Individual Discriminant Function Scores for Second Molars of Three Archaeological Groups.

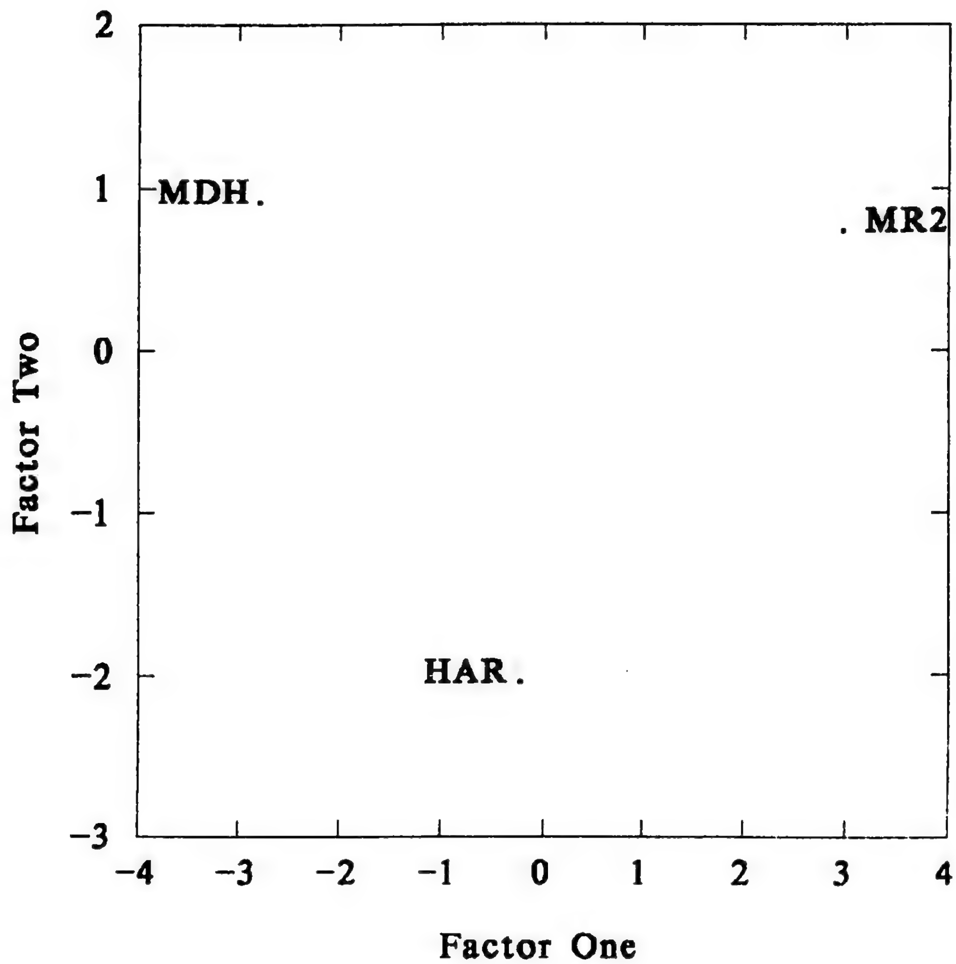


Figure 6.33. Two-Dimensional Ordination of Group Centroid Discriminant Function Scores for Second Molars of Three Archaeological Groups.

discriminant function are marked by high counts and relative percentages of small scratches, and by a relatively low percentage of large pits (Figures 6.32 and 6.33). By contrast, groups that receive a high negative score along the second function are marked by low numbers and percentages of small scratches, and by a high percentage of large pits. As indicated in Figure 6.33, the average values of these microwear variables (Table 6.2) are indeed more similar for Mahadaha and Mehrgarh, but distinctly different from the average values for Harappa. For example, Mahadaha and Mehrgarh second molars share similar values for the percentage of small scratches, while Harappa second molars exhibit very few small scratches.

Generally, the discriminant function analysis for the second molars appears to perform better than for first molars, especially with regard to the results of function one. Nevertheless, fairly good separation of the three groups in two-dimensional space was obtained for both molar tooth types.

In summary, the results from discriminant function analysis of the first and second molars are complementary to the significant results obtained from the multiple comparisons, and the results of the principal components analysis. The results of these multivariate analyses produce a very good separation of the three archaeological groups with regard to parameters of dental wear and microwear.

CHAPTER VII

DISCUSSION

Introduction

This chapter focuses on a discussion and interpretation of the results of the quantitative analyses from Chapter VI. The qualitative microwear pattern was summarized for each archaeological group in Chapter V and described broadly with regard to the flora, fauna, and food processing technology documented for each site. My principal emphasis in this chapter will be on discussing the quantitative comparisons of the dental microwear parameters and any associations with potential abrasives in the diet (e.g., extraneous grit from grinding stones, soil contamination, grit particle size, opal phytoliths). Also, I attempt to integrate the macro- and microwear evidence with faunal, floral, and artifactual evidence.

The first section compares dental wear and microwear between the groups in the South Asian sample, including trends or gradients in wear and microwear, and the use of the wear and microwear data to derive inferences on prehistoric diet and food processing technology. In some cases, archaeological data are used to provide explanations for the microwear pattern of a group. A section is also devoted to a discussion of the sex differences for microwear within the Harappa and chalcolithic Mehrgarh samples. A later section is devoted to a comparison of the prehistoric South Asian wear and microwear patterns to archaeological groups from the Middle East and North America, as well as to some of the primate data. Finally, I discuss methodological issues related to the collection of feature count data and the systematic use of micrographs produced with different instrument stage geometries.

Intergroup Comparisons of Dental Wear and Microwear

Trends Evident Between the Samples

As demonstrated in Chapter VI, several patterns are apparent from my analyses of the quantitative wear and microwear data. The mesolithic (Mahadaha) molar teeth generally exhibited a more severe degree of macroscopic wear than the agricultural groups from chalcolithic Mehrgarh or Harappa. The quantitative analyses of wear scores indicated no differences for macroscopic wear between the chalcolithic and bronze age groups. In general, the results from the intergroup comparisons were consistent with those reported by B. Holly Smith (1984), in which the dental wear of hunter-gatherers was significantly different from agriculturalists. Therefore, the wear scores analyses support the archaeological evidence for hunted and gathered foods comprising the Mahadaha diet, while more refined foods were predominant in the chalcolithic Mehrgarh and Harappa diets.

The significant microwear differences for first molars from the four archaeological groups were found predominantly for the density-related variables (feature count and feature frequency). As with the first molar teeth, most of the significant variables for second molars from three of the groups were also associated with the density of features (feature counts and frequencies). A consistent trend is present for an increase in the number of features and the number of scratches between the mesolithic and the neolithic periods, with a slight decrease in feature densities in the chalcolithic period, and with a further decrease in the bronze age. In some cases, feature densities at Mahadaha are very similar to those at Harappa. A somewhat similar trend is present for the number of large scratches, where the mesolithic site has relatively few, the bronze age site has significantly more, but both Period I and III at Mehrgarh have relatively high numbers of large

scratches. An even clearer trend is obvious for the densities of small and large scratches, when calculated as relative percentages. In this case, the mesolithic and neolithic first molars, and the mesolithic second molars, have relatively high percentages of narrow scratches, and the percentage gradually decreases from the chalcolithic period to the bronze age. An opposite trend is present for the percentage of wide scratches on first molars, with the largest percentage of wide scratches occurring on the Harappan molars. Also, a very clear gradient is present for progressively increasing percentages of large pits on second molars from the mesolithic period, through the neolithic period, and into the bronze age where the teeth have a relatively high percentage of large pits.

Significant intergroup differences in microwear feature dimensions, for pits and scratches on second molars, demonstrate a trend for increasingly larger features with the intensification of agriculture and animal domestication (Table 6.10). A consistent trend was observed for progressively larger pits between the mesolithic, chalcolithic, and bronze age groups. Average pit size ranged from a diameter of 4.5μm on the mesolithic second molars, increased substantially in diameter in the chalcolithic period, and reached a size larger than 9μm in the bronze age (Tables 6.1, 6.2). Also, the mesolithic group shared relatively narrow scratches with the chalcolithic group, while the bronze age group had the widest scratches. For example, the average scratch width was close to 3μm on the mesolithic and chalcolithic second molars, and greater than 4.5μm on the bronze age teeth. Similar trends were observed for scratches on first molars, but the results were not significant.

In summary, these trends or gradients in quantitative microwear parameters indicate that finer microwear features were common to hunting-gathering and incipient agricultural lifeways, whereas coarser features were typical of sedentary agricultural lifeways. Intermediate-size features are typical of the chalcolithic group, which is intermediate to the other groups in terms of cultural complexity and food processing technology (e.g.,

archaeological assemblage, diet, culinary practices). The relationships of these archaeological trends in feature size, type, and density to abrasives in the diet are discussed in the succeeding section.

When the data are examined by tooth type, it can be seen that the number of pits is slightly higher on Mahadaha and chalcolithic Mehrgarh (MR2) first molars than on the respective second molars, although a test was not conducted for significant differences in feature counts between the two molar types. Overall feature density (number of features) is also slightly higher on first molars than second molars from Mahadaha and neolithic Mehrgarh (MR3), despite the fact that the mesolithic teeth showed the severest wear of any of the groups in the sample. Excep for the neolithic sample, the other archaeological samples reveal relatively equal pit densities (percentage of total pits) on the two molar types, or slightly greater densities on the first molars (Tables 6.1, 6.2). This is contrary to evidence that chimpanzees exhibit a higher density of features, primarily pits, on more posterior teeth in the molar tooth class (Gordon 1980, 1982). It is also possible that the small samples used in my study and Gordon's may have contributed to the results. Ultimately, these results for the South Asian skeletal samples may be a factor of the functional age (Gordon 1980) and the degree of occlusal wear of the teeth from each group. In other words, the more severe the macroscopic wear, the greater the turnover rate is for microscopic wear features. Consequently, it may be difficult to discern molar type differences for densities of features, especially pits, among archaeological samples with moderate to heavy tooth wear. However, this really is not a cause for concern as long as only homologous teeth are used for intergroup comparisons (Gordon 1980, 1982).

In addition, my multivariate analyses demonstrated a significant association between the severe wear of Mahadaha second molars and low feature and scratch densities. An opposite association was observed for the chalcolithic second molars, which exhibited a low degree of wear but high feature and scratch densities. The Harappa group was

intermediate for these same wear and microwear parameters. Within each of the mesolithic and neolithic Syrian samples analyzed by Molleson and Jones (1991:536), decreased pit densities were recorded on the older and therefore more worn teeth. It is possible that the biomechanical interaction between macroscopic wear (i.e., removal of enamel) and the production or obliteration of microwear features, demonstrated for monkeys (Teaford and Oyen 1989a, 1989b, 1989c), is also a phenomenon among at least the most heavily worn archaeological sample from mesolithic Mahadaha. Although the role of paramasticatory activity (e.g., hide chewing) cannot be discounted from the high attrition environment during the mesolithic, dietary inferences can still be derived from the mesolithic sample. This is reinforced by data for the density of features of different sizes. For example, the Mahadaha molars of both types have higher relative percentages of narrow scratches than any other group, which are likely produced by the unique dietary and food production factors of the mesolithic period. Additional discussion of the high rate of tooth wear at Mahadaha and the implications for microwear scratch patterns is presented in the succeeding section.

At this point, it may be worthwhile to discuss the dental fluorosis, which occurred premortem, and possible postmortem diagenetic alteration of tooth enamel at Mehrgarh, and the implications for the qualitative and quantitative microwear analyses. In Chapter V, coarse surface damage to the occlusal enamel was described for two of the neolithic molar specimens and some of the chalcolithic Mehrgarh specimens (e.g., MR2-42-A1, A2). The dental fluorosis documented at neolithic Mehrgarh (Lukacs et al. 1985; see Chapter III) affected premortem the two individuals from whom the molar specimens were obtained for this study. In fact, some teeth contained enamel fluoride concentrations greater than 8,000 ppm, as a result of regularly drinking water contaminated by high levels of fluoride (Lukacs et al. 1985:190). The limited fluorosis in chalcolithic Mehrgarh teeth was suspected to be due to the younger age class for the MR2 skeletal series (Lukacs 1985b).

Many studies have noted that fluorapatite is much more brittle than normal apatite. Powers et al. (1973) have noted that brittle failure of enamel, especially with fluorapatite, can occur when abrasive hard particles of a very small size (radius < 2μm) come in high-pressure contact with individual enamel rods. In this case, with small hard particles the fatigue cracks from surface failure would propagate around the enamel rods, making the enamel appear to be brittle rather than exhibiting the normally ductile quality. Human fluoridated teeth have been shown to exhibit a high degree of abrasion (e.g., chipping), due to the less resilient and more brittle fluorotic enamel in subsurface layers of the teeth (Puech et al. 1988).

Diagenetic processes have been recorded in bone at Mehrgarh (Radosevich 1989a; personal communication 1992). These included the growth of various mineral crystals (e.g., Sr, Br) after water dissolved salts entered fine cracks and pores in the animal and human bone (Behrensmeyer 1978; Behrensmeyer and Hill 1980). The strontium crystals Radosevich observed microscopically were approximately 10 to 100μm in diameter, and produced extremely high concentrations of strontium in the bone cracks. In addtion, the crystal growth resulted in additional cracking and eventual breakdown of the bone, producing Stage I taphonomic destruction of bone (Behrensmeyer 1978). This diagenesis precluded any dietary reconstruction at Mehrgarh based on trace element analyses (Radosevich 1989a).

However, if diagenesis was the only factor in the production of the coarse enamel surface damage on some of the Mehrgarh molars, it would be expected to affect the entire crown rather than only facet or occlusal surfaces (Teaford 1988b). Because of the brittle characteristic of fluorapatite, tooth-tooth wear (Teaford and Runestad 1992) of teeth with high enamel fluoride concentrations may have produced more and larger pits than normal on wear facet and occlusal surfaces. If strontium and bromine laden groundwater at Mehrgarh had seeped into these large pits in the enamel of the occlusal surface or into

micro-cracks elsewhere on the crown, crystals of these salts could have grown large enough to cause fracture of the enamel prisms and sluffing of portions of the enamel surface. Therefore, the extensive coarse enamel surface damage on the MR3 specimens and on some of the MR2 molars (e.g., MR2-42-A1, A2) may be due to a combination of excessive pitting of some fluorotic occlusal surfaces, and diagenesis produced from postmortem infiltration into fine cracks and pits on the surface of the fluoridated enamel by water-dissolved salts of strontium and bromine. In any case, much of the observed coarse surface damage occurred postmortem because of its presence on non-occlusal surfaces of the crowns. Again, postmortem wear should not be restricted to the occlusal surfaces of teeth, but also does not necessarily affect the entire occlusal surface or crown. Ultimately, it should be emphasized that fluorosis and/or diagenesis at Mehrgarh did not alter the qualitative or quantitative microwear results, because I used non-affected portions of the occlusal wear facets for my analyses (see Chapter V).

Inferences on Diet and Food Processing Technology

Mahadaha

At Mahadaha, mesolithic faunal remains were from wild species of large and medium mammals, turtles, fish, birds, and some rodents. The absence of pottery, especially ceramic cooking vessels, or bitumen-lined baskets at Mahadaha may have precluded frying or boiling the flesh from these animals, which would have made it softer and easier to chew. However, it is still possible to boil in tight baskets, wood bowls, or skin bags (Erlandson, personal communication 1993). Unfortunately, remnants of such perishable artifacts have not been recovered from Mahadaha. Alternatively, the meat may have been eaten fresh after roasting over or upon coals in pit hearths, a practice engaged in by other aboriginal peoples until very recently (Macfarlane 1973). For instance, most of the recovered faunal remains were charred and showed butchering cut marks (Misra and

Pal 1980; Sharma 1975). Pit hearths were also documented at Mahadaha (Varma 1989). It is also possible that the meat was made into jerky by air-drying for later consumption, a practice that produces a very tough and fibrous product that can be very abrasive to tooth enamel (Taylor 1963). Either method of meat preparation could potentially introduce abrasive particles from ashes or soil contamination (Collins 1932; Lovejoy 1985; Walker 1978) into the mesolithic diet. Unfortunately, no data are available on the types and sources of grit particles that might help explain the distinctive small feature dimensions on Mahadaha molars. For example, it is possible that fine airborne dust could have contaminated food items that were air-dried during the dry season at Mahadaha. Airborne soil particles, capable of producing microwear on tooth enamel, have been reported from upper levels of the canopy of tropical forests (Ungar 1992a, 1992b; Teaford, personal communication 1993).

Cereal grains and seeds of grasses from wild rice and other plants were gathered during the mesolithic. These may have been smaller than many of the cereal grains from the agricultural sites, allowing them to be swallowed with very little mastication (Molleson and Jones 1991). Also, these small grains may have required little grinding to prepare flour. As an alternative to boiling, a dry muesli or a dry bread could have been prepared from the flour, both of which would have required chewing before swallowing (Molleson and Jones 1991).

The many stone mullers and querns at Mahadaha were probably used for dehusking the seeds and grinding them into flour. The relatively small size of the seeds may have required relatively little grinding after dehusking. This could have had two implications for hard particles in the diet: (1) pieces of the pericarp may have remained with the kernel and/or the dry, hard kernel itself may have only been partially pulverized (however, it is unlikely that either of these materials would be of sufficient hardness to abrade enamel); (2) tiny grit particles from the grinding stones may have remained in the prepared flour.

Chewing such small abrasive particles may have produced many of the narrow scratches and small-diameter pits on the Mahadaha molars, especially if the abrasive particles from the groundstone were less than 2μm in diameter (see Chapter VI). Evidence for such a scenario is provided by the relatively higher proportion of fine scratches, and lower proportion of large pits, on the mesolithic molars than those of the agricultural groups.

Flour cakes may have also been cooked by toasting or baking on stones laid in the coals of an open fire. Like roasting meat, this too may have introduced abrasive particles into the mesolithic diet, as has been shown for traditional Australian aboriginal populations (Molnar et al. 1983). Roots and tubers were commonly gathered during the mesolithic period in many parts of the Old World (Eddy 1991), although there is no palynological or other direct evidence for such plant materials at Mahadaha. If the occupants of Mahadaha gathered and consumed root crops, they also may have cleaned these foods only minimally of soil or grit contamination prior to consumption. The fibrous and rough-textured nature of such food items also would have contributed to the enamel wear potential of the diet (Molleson and Jones 1991). The rough-textured appearance of the enamel fabric of Mahadaha molars (see Table 5.2) would seem to argue against fibrous plant materials in the diet, because such materials commonly produce polished featureless enamel surfaces (Blaeuer and Rose 1982; Harmon and Rose 1988; Rensberger 1978). However, it is possible that fibrous vegetal material was included in the Mahadaha diet, but the high rate of wear combined with the many crisscrossed scratches on the facet surfaces may have obliterated any resulting polish, or made recognition of polish difficult.

This also illustrates a problem inherent to the subjective determination of dental microwear patterns. Chenopodium album (goosefoot) was documented at Damdama (Kajale 1991), and the young shoots may have also been eaten by the occupants of Mahadaha as greens, much as contemporary Gujaratis do (Weber 1992a). The seeds of Chenopodium are small (roughly 1.4mm average diameter) and may have been ground into

flour or cooked with little preparation (Weber 1992a) (see earlier discussion). Opal phytoliths are not present in any part of this plant (Piperno 1988). The potential for opal phytoliths in any Mahadaha root crops is unknown. Unfortunately, in the absence of dimensional data for grit particles from soil or groundstone tools, it is difficult at this time to infer a specific causation for the mesolithic microwear pattern. However, the fact that the Mahadaha groundstone artifacts are nearly indistinguishable from those of Mehrgarh and Harappa (Kenoyer, personal communication 1992; see discussion for Harappa below) would seem to indicate that very small abrasive particles in the diet were derived from other sources, although the use of fine-grained groundstone to prepare the small seeds at Mahadaha may have introduced larger quantities of small grit particles than at the other sites.

The qualitative Mahadaha microwear pattern of crisscrossed transverse scratches, with obliteration of older scratches by newer ones, can be partially attributed to the biomechanics of occlusal contact for teeth with reduced cusp height. Hinton (1982:112) discussed the relationship of food preparation and consistency to the frequency of chewing strokes and the magnitude of masticatory forces required for reduction of the food bolus. According to Hinton, a rugged diet of seeds, nuts, wild plant foods, and small sometimes unboned animals in Archaic (6000-500 B.C.) Tennessee Valley Indians would require a large number of chewing strokes, high occlusal forces, and possibly lateral excursions of the mandible in order to fully masticate such a tough, fibrous diet. Other investigators have also documented an association between lateral excursions of the lower jaw and the mastication of tough or fibrous foods (e.g., Byrd et al. 1978; Campbell 1925, Gibbs et al. 1980; Weijs and deJongh 1977). It is also possible that the transverse scratches were produced by less vertical and more horizontal occlusal contact than occurred during "lateral gliding" of the upper and lower molars, as documented in older Australian aborigines (Beyron 1964).

Neolithic Mehrgarh (MR3)

During the neolithic period (Period I) at Mehrgarh, presently extinct species of wild ungulates and other large and medium game, predominantly sheep, goats and cattle, were hunted for food. The domestication and herding of goats was practiced during the earliest part of the neolithic period, and occurred for sheep and cattle during the late neolithic. In contrast to the mesolithic, once animals were domesticated and herded an animal could be killed, butchered and eaten when desired, and the need to air dry and preserve the meat may not have been as great. Therefore, the neolithic inhabitants would not have had to chew the tough, abrasive jerky that may have been a feature of the mesolithic diet. Presumably, the meat of these animals was roasted over or upon coals in a hearth, although it is unclear whether any bones were charred, as at Mahadaha. Like Mahadaha, the roasted meat may have been contaminated with small abrasive soil particles, gritty ashes, or by airborne soil during the dry season. The fact that MR3 and Mahadaha molars share similarly high proportions of very fine scratches and low proportions of coarse scratches indicates that similar methods of preparing and cooking meat may have been practiced by neolithic and mesolithic peoples. Soil samples were collected from in and around the burials Mehrgarh and Harappa (Lukacs, personal communication 1993) for use in trace element analyses, and from around the mound at Harappa for additional chemical analyses (Dales and Kenoyer, n.d.-a). However, the characterization of soil grain size or morphology was not incorporated into the research design of this study, and the usefulness of these kinds of data was realized only at a later stage of the study. Such data should be collected in future microwear analyses.

At neolithic Mehrgarh, botanical remains are indicative of a mixed diet of wild and domestic cereal grains. Naked (wild) six-row barley was the predominant cereal grain during this period, while hulled varieties of barley and naked and hulled wheats formed

only a small component of the neolithic diet. The fruit of the Indian jujube, and possibly the date, were also part of the neolithic diet. According to Molleson and Jones (1991), the size of grains from cereal crops in the neolithic of Syria was larger than in the mesolithic, and would have required more processing with grinding stones prior to their being cooked and consumed. This extra grinding had the potential for contaminating the flour with abrasive particles from the stone tools (discussed below). Perhaps this was also true at neolithic Mehrgarh, especially for the hulled barleys and wheats. Piperno (1988) reports that monocotyledonous plants, such as the gramineae (grasses and cereals), often have abundant and discrete deposits of silicon (silicon phytoliths) in many parts of the plant body. Emmer and einkorn wheat (Triticum dicoccum; T. monococcum) and two-row barley (Hordeum distichum) contain significantly greater amounts of silicon phytoliths in their glumes (the husk or bract) than in their leaves, but data on the size of the phytoliths is unavailable and it is unclear whether they also occur in the seeds of these or other wild or domesticated varieties of wheat and barley (Piperno 1988). It is possible, but purely speculative, that incomplete threshing of the grain from the naked six-row barley allowed pieces of the bract to remain with the seed head. If this chaff was ground into flour with the grain, it would have potentially introduced phytoliths to the flour. Plant phytoliths have a well-documented ability to produce enamel microwear (e.g., Baker et al. 1959; Walker et al. 1978). Whether this also occurred at neolithic Mehrgarh and was responsible for the unique microwear pattern, such as the high density of features and scratches, cannot be determined based on the current palaeobotanical evidence. The consumption of greens from herbaceous plants, which are also sources of phytoliths, may have been practiced during the neolithic, but botanical evidence is lacking for these because archaeological interest has centered on the cereal crops.

Ceramic cooking vessels were not present during the early neolithic period, but evidence of bitumen-lined baskets (Allchin and Allchin 1982) indicates that some food may

have been cooked, probably through boiling by placing heated rocks inside the container. Other types of perishable cooking containers also may have been used, but artifactual evidence has not been recovered. Therefore, it is possible that the cereal grains were cooked in the form of a gruel, whose soft consistency would not have the potential for producing microwear. However, baking a cake of flour on the coals of a hearth would be capable of introducing small abrasive particles to the diet, as with the roasting of meat.

Many stone grinding tools were found at neolithic Mehrgarh within dwellings and in graves as ritual offerings. The former were probably used for processing vegetal foods, but the latter may have been used for pulverizing red ochre used in burial rituals (see Chapter III). These groundstone artifacts have received little attention from South Asian archaeologists. However, a preliminary analysis and description of material type indicates that the stone tools used for dehusking and grinding cereal grains were of primarily fine to medium-grained basalt, quartzite, and sandstone, although coarse-grained grinding stones may have also been used for these purposes (Kenoyer, personal communication 1992). Metric and morphological data for grit particles, and information on botanical remains, from the grinding stones have not been collected or were unavailable during this study. This lack of data means that the mere presence of such tools may not strictly correlate with the amount of extraneous grit in the diet (Teaford, personal communication 1993).

Other factors may have also played a role in the production of the neolithic microwear pattern. Perhaps the microwear trend between the mesolithic and neolithic for an increased number of large scratches (similar to Period III), along with the dramatic increase in the feature and scratch counts during Period I were produced by tooth-food-tooth contact involving the stones of dates or possibly jujube fruit, or to coarse grit particles from grinding the cereal grains into flour. For example, fruitstones of the jujube (Zizyphus mauritiana) average approximately 7mm in diameter, whereas the date stones are considerably larger (Weber 1992a). The tiny jujube stones are relatively large in relation to

microwear features on the MR3 teeth, but their hardness would have the potential for creating large scratches through 'plucking' action on the ends of enamel prisms (Teaford and Runestad 1992). Therefore, the consumption of this fruit during the neolithic period may be one contributing factor to the high density of large scratches on molar facets. However, the fact that the Period I teeth had the highest feature and scratch counts of all the groups in the sample is difficult to explain from the archaeological evidence available at this point. The microwear data for MR3 reinforces the faunal and floral evidence for a mixed diet, and therefore the high prevalence of dental calculus for the neolithic inhabitants of Mehrgarh must remain an anomaly (Lukacs 1983b, 1985b) (see Chapter III).

Chalcolithic Mehrgarh (MR2)

At chalcolithic Mehrgarh, domestic species of cattle, sheep and goats were herded and the meat butchered for consumption. Also, several wild species of ungulate, as well as wild boar, were hunted during the chalcolithic. Fully domestic varieties of wheat (e.g., *Triticum monococcum*) were the predominant cultivar during the chalcolithic period, but barley (e.g., *Hordeum distichum*) and oats (*Avena* sp.) were also grown to some extent. The fruit of the jujube was eaten as well, but not dates.

The significance of grinding stones and pottery to food preparation at chalcolithic Mehrgarh was discussed in Chapter III. Numerous groundstone artifacts (pestles, mortars, and grinding stones) from the chalcolithic period were used to grind wheat and other grains into flour for use in baking a bread or cake. According to Kenoyer (personal communication 1992), the MR2 groundstone tools were made from fine to coarse-grained basalt, quartzite, and sandstone, and are essentially indistinguishable from those from MR3 or Harappa. As with Period I, it is possible that only the grinding stones of fine to medium-grained material were used for processing grains.

During the chalcolithic period, fine wheel-thrown ceramic ware was produced in

quantity and used as cooking and storage vessels. However, the contents of this pottery were cooked by placing heated stones inside, much as was practiced during the neolithic period and possibly the mesolithic, rather than heating the contents of a pot over a flame (Jarrige 1985). Boiling the meat or preparing the wheat and barley flour as a gruel would have softened the texture of the food. Thus, fine abrasives from wood ashes or soil contamination, introduced when a cake of wheat (chapati) is baked on coals, were not present or were less abundant in the chalcolithic diet. Instead, a chapati made from wheat or barley flour was baked on a heated stone slab. Undoubtedly, the size of the grains from the MR2 domesticated cereals was larger than the wild grass seeds of the neolithic and mesolithic periods. As in neolithic Syria (Molleson and Jones 1991) and possibly Mehrgarh, the larger grains would have required a greater degree of processing with the groundstone manos and metates.

As previously discussed for Period I, the extensive use of fine to medium-grained grinding stones during Period III would have contaminated the flour with relatively larger grit particles (i.e., > 2μm) than abrasive particles derived from soil or wood ash. This may account for the relatively large average pit diameter on the Period III second molars. If this assumption is correct, then the fact that the average pit size is still smaller than at Harappa, although the high pit counts were nearly identical, suggests that the use of grinding stones at chalcolithic Mehrgarh was more limited compared to the bronze age site. Chalcolithic Mehrgarh also shares relatively low percentages of small scratches and high percentages of large scratches with Harappa, which may be indicative of similar abrasive particles in the diet. However, the chalcolithic Mehrgarh microwear pattern is unique for the very high densities of features and scratches when compared to either Mahadaha or Harappa, but similar to the first molars from Period I. An additional distinction between MR2 and Harappa lies in the narrow scratches on second molars, which were nearly identical to those at Mahadaha, but significantly different from the wide scratches on Harappan molars.

Perhaps, this evidence signifies the presence of very small grit particles derived from sources such as soil contamination of roasted meat, or the inclusion of fibrous plants in the chalcolithic diet. In Chapter V, the enamel fabric of the first molars was described as relatively smooth and polished (Table 5.2), which implies the consumption of tough fibrous plant foods (e.g., Blauer and Rose 1982), perhaps as a form of 'greens,' by the occupants of chalcolithic Mehrgarh. However, no such plants have been documented in the floral remains (e.g., seeds, pollen) of Period III levels (Meadow 1989). At this point, a satisfactory explanation for the enamel polishing or the presence of very narrow scratches is not forthcoming.

Harappa

At bronze age Harappa, meat was obtained from domestic bovids (cattle, sheep, goat) and pigs, as well as many species of wild fauna (Meadow 1991a, 1991b). Although speculative, perhaps the meat from wild game was tougher and more fibrous than meat from domestic livestock, and/or was roasted on coals in a traditional fashion. Either scenario would have the potential for producing variation in the microwear pattern, the first through possible plucking of enamel prisms, and the second through scratching and pitting of the enamel surface by abrasive particles from the soil or wood ashes, similar to that observed in hunter-foragers. However, data on soil particle size and composition have only recently become available (Dales and Kenoyer, n.d.-a) and thus were not incorporated in my analyses. Meat probably supplemented the diet of Harappans, especially of males (see discussion in next section). Instead of the above cooking method, meat may have been more commonly prepared using any of several methods: boiled in a ceramic pot (described below); baked in an oven; roasted on a spit; or fried. All of these methods would have produced relatively soft food free from grit contamination. Only the feature and scratch counts are similar between the Harappan and Mahadaha molars, indicating

perhaps the more common microwear pattern for archaeological groups (Teaford 1991) when compared to the unusually high feature densities for the two Mehrgarh groups, rather than any specific dietary affinities with each other such as roasting and eating wild game.

Fully domestic varieties of wheat, barley and various leguminous plants were cultivated at Harappa during the Urban Phase. The size of these grains was undoubtedly larger than the wild grass seeds in the mesolithic and neolithic diets Molleson and Jones 1991; Weber 1992a, 1992b). The seeds of wild grasses, recovered recently at Harappa (Dales and Kenoyer, n.d.-a), may have been included in the diet or used as forage for cattle and other domestic livestock. The presence of herbaceous "weedy" species of plants (e.g., Chenopodium, Trianthema) could indicate that they were consumed as a green vegetable in times of food scarcity, as is still practiced in Gujarat (Weber 1992a). Ceramic vessels are a ubiquitous part of the archaeological assemblage during the Urban Phase at Harappa. The vessels range in size from small oil lamps to large utilitarian storage jars, and included many used for cooking purposes. The pottery and other archaeological and dental pathological evidence (e.g., the high rates of dental caries, dental calculus, and enamel hypoplasia) indicate that occupants of Harappa primarily consumed diets of soft, sticky, high carbohydrate foods prepared from cereal grains in the form of a gruel, chapati, or bread.

A preliminary analysis of the numerous groundstone artifacts from the Mature Harappan levels has been undertaken by Kenoyer (see Chapter III), but a systematic analysis of the function of these artifacts (Miller 1991) and publication of the results are still pending. The preliminary evidence suggests that manos and metates used for plant processing were of medium to fine-grained lithic materials, such as quartzite, sandstone, and basalt. However, the coarse-grained quartzite and sandstone grinding slabs may have functioned more efficiently for grinding the cereal grains into flour, because the coarse granular surface of the stone would have provided more cutting edges than finer-grained

lithic materials and probably became filled with starchy material from the grain less frequently. In the latter case, renewal of the grinding surface by pecking with another stone tool would create fresh cutting edges, through fracture and exposure of mineral grains, which would be larger for coarse-grained grinding stones. As a result, the possibility of large grit particles in the flour, especially sand grains from the use of sandstone querns, may have been a contributing factor to the especially high percentage of large pits on Harappan second molars. The extremely low percentage of narrow scratches and high percentage of large scratches on Harappan first molars also reflects the preponderance of large abrasive particles in the Harappan diet. It is also possible that tooth-food-tooth contact involving pits from the jujube contributed to the high density of wide scratches, as was hypothesized for the neolithic group. The terra cotta manos found at Harappa and many other Harappan sites, although possibly used for food processing, would have produced very fine and almost silty grit particles (Kenoyer, personal communication 1992). Perhaps these fine abrasive particles were capable of producing the smooth polished enamel exhibited by the first molars. However, the botanical evidence for wild grasses and herbaceous plants at Harappa may be an indication that wild species of tough, fibrous plants were also being gathered and consumed at Harappa, as has been hypothesized for Harappans throughout the core and peripheral areas of the Harappan tradition (Weber 1992a). If so, the consumption of such wild plants by occupants of Harappa may have contributed to the enamel polishing of their molars. Data is lacking for phytolith presence in plants documented at Harappa, either because investigations have not yet been conducted or because of poor phytolith production by these plants (Piperno 1988). Therefore, the potential contribution by phytoliths in any plants eaten as greens at Harappa to the high density of large scratches is unknown. With regard to molar differences, the fact that the second molars exhibited a rougher-textured enamel fabric may indicate masticatory differences for the two molar types, whereby the initial comminution of an

ingested food bolus takes place between the upper and lower first molars, while grinding and further processing of the bolus takes place between the second molars.

Within Groups Sex Differences

The analyses of sex differences for molar microwear within the Harappa and Mehrgarh samples must be considered exploratory and the results preliminary, because of the very small sample sizes involved. Neverthelesss, it is possible to draw some intriguing inferences, especially for the Harappa sample. For the Harappa molars, the significant sex differences exhibited for some of the microwear parameters, such as the significantly greater pit density and width on second molars of females, may indicate social stratification of the sexes at Harappa. The second molar appears to be a key tooth in the sex comparisons, because most of the significant differences occurred for this tooth. Because the second molar is involved in more crushing activity than the first molar (Gordon 1980, 1982), it would appear that females ingested more and larger grit particles than males. As proposed in Chapter I, these results lend further support to the notion that some female individuals were accorded differential treatment within Harappan society, especially with regard to diet. Gender-based status differences may not, however, be indicated by artifactual evidence (e.g, grave goods, ornamentation) as judged by preliminary evidence from recent excavations (see Chapter III). Perhaps women had frequent access to food items that were of a coarse nature or prepared in a way that introduced a greater amount of extraneous grit, such as with the stone querns and mullers recovered from Mature Phase levels at Harappa. In contrast, the two males had significantly lower pit widths than the females, indicating that they may have consumed more meat than females. Ethnographic studies of contemporary foraging and farming populations provide evidence for more frequent access to certain food items, especially high carbohydrate foods, among females who spend a large amount of time in the settlement area (Walker and Hewlett 1990).

Gender-based differences in caries and diet have also been reported for many prehistoric populations (e.g., Walker and Erlandson 1986). Also, trace element analyses of human and animal bone from Cemetery R37 revealed gender-based dietary differences, despite severe diagenesis (Radosevich 1989b, 1990). As discussed in Chapter III, sexual dimorphism is also present at Harappa for paleopathological indicators of dental health (Lukacs 1992, personal communication 1991). For example, the incidence of enamel hypoplasia among females is significantly greater than for males. Harappan females also had a considerably greater prevalence of dental caries and ante-mortem tooth loss than males, suggesting a low protein-high carbohydrate diet for females. Although the microwear data is preliminary, it adds support to these other lines of evidence indicating sex differences for diet at Harappa.

Significant sex differences were not found for any microwear parameters associated with chalcolithic Mehrgarh molars. While there might be a suggestion of differences, analyses of larger samples are needed.

Comparison of South Asian Sample with Other Archaeological Groups

Comparisons of the results from the qualitative analyses of the dental microwear for the four archaeological groups were addressed previously in Chapter V. The comparative sample for the qualitative microwear analyses included prehistoric skeletal series from the southeastern United States (e.g, Blauer and Rose 1982; Harmon and Rose 1988; Marks et al. 1985); Alaska, northern Canada, and the southwestern United States (Gordon 1986); the southeastern Atlantic Coast of the United States (Teaford 1991); and Nubia and Egypt (Puech et al. 1983). The comparative sample also included fossil hominids and extant primates (Teaford 1988a, 1988b).

Comparison of the quantitative microwear results from the South Asian sample with other prehistoric populations is limited by the dearth of other quantitative and systematic

microwear analyses of archaeological assemblages, especially of studies that emphasized posterior tooth wear produced by alimentary factors. For example, the extensive comparative work of Rose and colleagues cannot be used, because of the very high magnification used (1500x), the semi-quantitative nature of the analyses, and the lack of descriptive statistics. For data most directly comparable with those from my study, I use work by Bullington (1988, 1991), Gordon (1986, 1990), Molleson and Jones (1991), and Teaford (1991). Statistical analyses of the inter-sample differences were not conducted because of methodological differences and/or the unavailability of the original raw data. Therefore, my comparisons emphasize the description of the results (e.g., average values for microwear parameters) from the other archaeological groups and the construction of an explanatory framework using information for diet, food processing, and subsistence systems from the various archaeological assemblages.

On the southeastern Atlantic Coast, Teaford (1991) found a microwear gradient between the earliest precontact sites and the late contact sites for scratch width and the number of pits. Crushing/grinding facets on first molars from the precontact sites had more pits and wider scratches than the late contact sites, while teeth from the early contact sites were intermediate. The results suggest a gradual dietary shift over time from the hunting and gathering of wild foods, including marine resources, to later agricultural intensification. Presumably the large quantities of shellfish gathered and eaten by the precontact groups contributed large hard particles (e.g., sand grains), which produced the significantly wider scratches and increased enamel pitting on the molars. The South Asian skeletal sample is not directly comparable for pit densities because different wear facets were used in the two studies and crushing/grinding facets yield higher pit counts than shearing facets (Gordon 1980; 1984d). Although width measurements of scratches should not be affected by inter-facet differences, the reliance on untilted fields in my study, which may not reveal extremely fine scratches, and methodological problems limiting the

minimum measurable dimension (see Chapter IV) means that my methods are unable to attain the fine resolution (widths < 1 micron) yielded by Teaford's methods. Therefore, width measurements from the two samples should be compared cautiously so that more than just methodological differences are documented (Teaford, personal communication 1993). Comparing scratch widths of the Georgia-Florida coast sample with the South Asian sample reveals that widths of all the South Asian groups are uniformly greater than those in the coastal sample. Therefore, this suggests that the South Asian groups as a whole were ingesting larger hard objects than the coastal groups from the southeastern United States. The difference in scratch widths is particularly striking when the agricultural groups are compared, possibly representing true differences in functional and techno-cultural processes rather than methodological differences. Both of the committed agricultural groups from South Asia (MR2 and Harappa) have considerably wider scratches (3.9μm and 4.6μm, respectively) than the late contact Atlantic Coast groups (1.2μm). This may be explained by the fact that the latter used wooden manos and metates to grind maize into flour, thus minimizing the amount of dietary grit from this source, although abrasive particles were still being ingested with shellfish. When the total number of features is compared between the samples, Mahadaha and Harappa have slightly fewer, but Periods I and III at Mehrgarh have considerably more features than any of the coastal sites. Therefore, both Mehrgarh groups were possibly ingesting more abrasive particles in their diet than the coastal groups. Nevertheless, the small size of the South Asian samples, especially for Mehrgarh Period I, suggests that the results of these comparisons be accepted cautiously.

The quantitative microwear data for a sample of mesolithic and neolithic groups from Syria (Molleson and Jones 1991) were collected from "shearing regions" on permanent upper first molars, but the SEM analysis was done at low magnification (180x). This and other differences in the research protocols for the Syrian and South Asian studies

increases the problem of data compatibility. For example, the average pit diameters on "Region 5" are less than half the size of the mean pit widths for either the South Asian sample or Teaford's (1991) coastal sample. This is probably due to methodological differences in pit recognition, as small depressions on the Syrian teeth were counted as separate pits (Molleson and Jones 1991:530, Figure 3), rather than as a composite pit (see Chapter IV). Pit densities are also dramatically higher in the Syrian sample, because of the greater field of view, and therefore larger surface area, generated at low powers of resolution with the SEM. The use of low magnification may have also limited the number of fine scratches detectable on the micrographs. However, a cautious comparison of the inter-group differences within the Syrian and South Asian samples maintains internal consistency and can still provide some insights. For example, the two samples each showed that a dietary shift in the types of grains eaten had a greater effect on the dental microwear than a shift in the types of meat consumed. Mesolithic sites from both studies showed smaller pit widths and narrower scratches than the neolithic sites, as a result of small abrasive particles in the diet, although Mahadaha may have had a generally harder diet. The neolithic South Asian group was also broadly similar to the Syrian neolithic groups in their increased feature densities compared to the mesolithic groups, but the change at neolithic Mehrgarh involved increases in the density of total scratches and in scratches of different size, not the change in pit density shown for the Syrian sites. As with the Syrian neolithic, occurrences of similar grains in the chalcolithic and bronze age of South Asia indicates that the microwear differences can be attributed to changes in food preparation, and possibly to the increased variety of foods available in the diet.

The preliminary nature of Gordon's (1986, 1990) studies on prehistoric human microwear precludes its use as a comparative quantitative study (Gordon, personal communication 1990). Also, because of different protocols it is difficult to compare the metric data, even if it were available, from the North American prehistoric groups with the

South Asian groups. However, the numerous fine scratches and small pits for the Eskimo molar teeth is a pattern broadly similar to the situation at Mahadaha. The exclusive meat diet of the Eskimo is corroborative evidence for meat as a principle contributing factor in producing the unique microwear at Mahadaha. The broad scratches and large pits found on the molars of Zuni, whose dietary staple is ground maize, indicates that similar features exhibited by the chalcolithic Mehrgarh and Harappan molars are at least partially due to a diet based on prepared cereal grains.

It is difficult to compare the South Asian results directly with Bullington's (1988, 1991) microwear data for Middle Woodland and Mississippian deciduous teeth, because primarily age-related frequency data were collected and because of the structural and chemical differences between deciduous and permanent enamel (Maas 1988; Scott and Symons 1982). However, she found that total feature frequencies of Middle Woodland juveniles in the youngest age class were higher than for Mississippian teeth, an indication that the Middle Woodland juvenile diet was harder and more variable than the Mississippian diet. Except for Mahadaha, the South Asian results are similar in the decrease in total feature frequencies with increasing agricultural intensification (HAR<MR2<MR3). Harappa permanent molars also showed sex-based variability in microwear, which would not be expected in the juvenile Mississippian group.

Ungar's (1992a, 1992b) study of modern primates is useful from a comparative perspective because it emphasizes the ability of silica to produce abrasion on tooth enamel. His study revealed that interspecies differences in dental microwear were associated with differences observed in the wild animals for feeding height, and the method and proportion of time spent consuming a specific food item. Scratch breadth was a function of grit particle or phytolith size, which were associated with wind-borne siliceous soil particles or with silica-rich leaves, fruits, and plant stems in the diet, respectively. Wider scratches were produced by the silicon phytoliths, which were larger than the small clay particles

(soil) that produced narrow scratches. In the South Asian prehistoric sample used in this study, it was also hypothesized that small particles of soil or ash, possibly siliceous in content, produced narrower scratches than the larger abrasive particles derived from groundstone artifacts.

Methodological Considerations

Collection of Grand Total Feature Counts

When using micrographs produced with a 'normal' instrument stage geometry for the principle data collection, it is probably not necessary to collect Unmeasured Count data from 'tilted' micrographs for compiling grand total feature counts (see Chapter IV). Sufficient information can be gleaned from the total feature counts alone, which distinguished between the groups as successfully as the additional information provided by the grand total counts. For example, the mean values for the grand total feature frequencies on second molar teeth are within three to four percentage points of the corresponding total frequencies for any of the groups. Of course, the collection of data from tilted micrographs only would alleviate these concerns, but would require attention to the phenomena of feature foreshortening (see discussion below).

Use of Tilted versus Normal Micrographs

Paired-sample t-tests were used to compare the length and width measurements for individual features on normal micrographs and tilted companion micrographs from half ($n = 5$) of the Mahadaha specimens, consisting of two first molars and three second molars. The comparisons revealed significant differences ($P < 0.05$) in feature widths for a single set of paired fields (V2-3711/V2-3713). Four out of five of the paired fields showed no significant interfield variation in feature width. Therefore, the chances are small (1 out of 5, in this case) that width measurements taken from normal micrographs will skew the

specimen or group averages. The relative proportions of features sorted into small and large size categories will also not be skewed when collected from normal micrographs. For example, the percentage of grand total scratches on first molars increased only minimally from that of the percentage of total scratches. However, the raw counts of the finer scratches may be abnormally low because of the likelihood of not observing and measuring such features, due to the diminished detail on normal fields (see Chapter IV). For similar reasons, average widths may be slightly greater for the untilted fields compared to the tilted fields.

Scratch lengths between normal and tilted micrographs varied as much as five percent. Two out of five of the paired field comparisons (U2-3512/U2-3514, W2-3911/W2-3913) yielded significant interfield differences in feature length ($P < 0.05$). In other words, there is a moderate chance (2 out of 5, in this case) that some tilted fields will yield feature lengths up to five percent shorter than those collected on the same features on normally-tilted micrographs. This could be problematic, especially when statistically comparing these data with those from other studies, although feature length was used in this study only for categorizing features by shape (i.e., ratio of width:length) and not as a microwear variable for analysis. One way to avoid any problems of inter-sample or inter-study comparability would be to use a higher level of significance in statistical analyses (e.g., 0.01 instead of 0.05) (Ungar, personal communication 1993).

CHAPTER VIII

CONCLUSIONS

As described in Chapter I, this research project was conceived and conducted with several objectives in mind. First, I wanted to examine the dental microwear of prehistoric skeletal series from South Asian sites that showed varying degrees of sociocultural complexity and agricultural intensification. If distinctive patterns of dental microwear were documented, I hoped to identify associations between the microwear patterns and prehistoric diets, food processing technologies, and subsistence patterns. Finally, I wanted to construct a dental microwear model for drawing inferences and formulating predictions about the diet of other prehistoric populations. Toward these ends, I offered several hypotheses which which this study was designed to test. As is typical of many research projects, several of the hypotheses were successfully tested while others remained unanswered. Also, along with the answers to questions that were posed come many new research questions for future study.

My study is significant for several reasons. First, it is one of the few studies to use a moderate-size sample of prehistoric human teeth for the systematic collection and analysis of quantitative microwear data. Also, it is the first study to investigate the dental microwear in skeletal series from the Indian subcontinent. As a result, the study has identified patterns of intra- and interpopulational variation for dental microwear among prehistoric South Asian populations, and extended our knowledge of prehistoric diet and food processing in the Indian subcontinent. Third, I have identified preliminary evidence for sex differences within an archaeological sample, differences that may be related to dietary variation based on gender or status, but also showed that the intragroup variability did not overwhelm the

intergroup differences. Finally, multivariate analyses (principal components, discriminant functions) were successfully used to test the variability within the microwear data sets, and demonstrated distinct separation between the groups.

Microwear Trends Within the South Asian Sample

The hypothesis I proposed in Chapter I for an absence of dental microwear differences between the four South Asian archaeological groups was disproven by my study. Significant differences were found between the sites based on different sets of microwear variables. Regarding qualitative microwear patterns, the characteristics of scratch margins and the appearance of the enamel fabric produced reasonable separations for some of the groups, but could not be explained for others. Feature densities (total features, pits, or scratches), whether judged subjectively or quantitatively, were far more likely than feature widths to reflect the true separation of the groups (based on the archaeological record), although the densities of pits or scratches sorted by size were able to explain a significant amount of the variation between the groups.

Ultimately, these results reinforce previous contentions that the texture of foods in the diet, as well as the abrasiveness of foreign particles of grit, are both contributing factors in the production of microwear on the occlusal surfaces of molar teeth. The results suggest that a dietary and economic transition occurred in the greater Indus Valley between the 7th to 3rd millenia B.C. This transition involved hunter-gatherers who consumed roasted wild game, small seeds of wild grasses, tough fibrous herbaceous plants, and root crops to agriculturalists who had a diet dominated by soft, starchy cereals, supplemented with tough and fibrous wild plants, and occasionally the meat of wild game. Specific conclusions for each site and hypotheses that remain to be tested are offered in the following sections.

1. My qualitative analyses of the Mahadaha microwear pattern suggest that the rough-textured enamel fabric and pattern of crisscrossed scratches probably reflect the high rate of

wear, as a result of the mastication of tough, fibrous wild plants. The normal enamel polishing produced by such a diet was obliterated by the numerous fine scratches and small pits, attributed to the ingestion of small abrasive particles from the practice of cooking meat and cakes made from the seeds of wild grasses directly on coals. Dietary grit may have also been derived from the use of fine-grained groundstone tools to dehusk and grind the small wild seeds.

2. The neolithic Mehrgarh (MR3) molars exhibited a microwear pattern of numerous narrow to large scratches and a moderate density of small to medium pits. While the fine scratches may indicate that meat was roasted on coals, with accompanying contamination by small grit as at Mahadaha, the extremely high density of large scratches may indicate a diet including large amounts of cereal grains prepared with grinding stones. The enamel polishing cannot be explained at this time, because the occurrence of tough fibrous plants has yet to be documented. The very coarse enamel surface on portions of wear facets was suggested to be a result of dental fluorosis, tooth-food-tooth contact involving hard fruit pits, or tooth-tooth contact, and postmortem diagenesis. Perhaps the intermediate features of the neolithic microwear pattern represent the transitional nature of an incipient agricultural lifeway whereby a mixed diet was being consumed. Ultimately, these conclusions must be accepted cautiously because of the constraints of the small sample size.

3. The chalcolithic Mehrgarh (MR2) microwear pattern of relatively large pits, high feature density (features, pits, scratches), and high percentages of large scratches suppports the archaeological evidence for increased reliance on an agricultural subsistence system involving the consumption of domestic wheats and barleys prepared with coarse groundstone tools. Variability in scratch morphology and quantitative microwear parameters, such as the density of pits and the width of large pits, probably represent dietary differences by age or sex, but the latter is merely speculative because the differences

were not significant. As with Period I, the polished enamel surface on the Period III molars remains inexplicable, barring new palaeobotanical evidence for wild plant consumption. Reanalysis of Mehrgarh soil samples for plant pollen and silica phytoliths may provide evidence for wild herbaceous plants.

4. Harappa shares high percentages of large scratches and pits and other microwear parameters with MR2, indicating the reliance on a soft, starchy vegetarian diet of high carbohydrate processed grains. The preponderance of large features on the molars refutes the theory for centralized milling areas using wooden mortars and pestles, but supports the recent hypothesis for the use of coarse-grained groundstone tools to grind the domestic grains into flour. The enamel polishing on the wear facets, the result of chewing tough fibrous plants, supports recent evidence that wild species of plants were being gathered and consumed at Harappa. Although the microwear variability at Harappa refutes the original hypothesis for decreased dietary variation (i.e., a more homogeneous diet) with increasing sociocultural complexity, the variation was found to actually be generated by sex differences in diet.

5. Some general patterns can be predicted with regard to dental microwear, dietary inferences, and implications for food processing in South Asia from the 7th to the 3rd Millenium B.C. I believe skeletal series from other Mature Phase Harappan sites throughout the core area (e.g., Mohenjo-daro) will display a microwear pattern similar to that of Harappa, because of the well-documented similarities in faunal and botanical remains and food processing technology. Also, a high degree of variability in the microwear parameters would still be expected, because of dietary differences based on status and/or sex. Sites from the peripheral area of the Harappan tradition are predicted to show some differences from the Harappa microwear pattern, such as possibly smaller pits, because of differences in some cereal crops (e.g., millets at Rojdi) and their method of preparation. Chalcolithic and late pre-Harappan sites are predicted to show a dental

microwear pattern nearer to that of MR2 than Harappa, on the spectrum of South Asian microwear variation, but this would depend on the type of cereal grains, wild plant gathering, and food processing techniques practiced. The dental microwear of mesolithic and neolithic skeletal series (e.g., Damdama, Sarai Nahar Rai, Kile Gul Mohammad, the Iranian site of Shahr-i Sokhta) is predicted to resemble that of Mahadaha and MR3, especially for the high density of narrow scratches and small pits. Variations in the texture and appearance of the enamel fabric is expected, because of local and regional differences in the dietary contribution from wild plants.

6. The analysis of microwear variability within small mixed-sex samples from Harappa and chalcolithic Mehrgarh revealed significant differences in microwear parameters among males and females from Harappa. The results suggest that Harappan females consumed more high carbohydrate foods than males. In contrast, Harappan males consumed more meat as a normal part of their diet. These differences provide preliminary evidence for social stratification of the sexes at Harappa, which had implications for dental disease and other sexual dimorphic characters among occupants of Harappa. However, future research into these differences requires larger samples than used in my study.

7. The South Asian dental microwear model also can be used to derive predictions for microwear patterns in other prehistoric South Asian populations as well as prehistoric skeletal series from other parts of the New and Old Worlds. For example, skeletal collections from coastal archaeological sites of Oregon should show more evidence of grit in their diet (more and larger pits, larger scratches, due to sand in shellfish) than would interior cultures of the Great Basin. Due to their greater dietary reliance on roots, tubers and small seeds from wild species of plants, the latter groups would be expected to exhibit a significantly different type of dental microwear pattern, consisting of fewer and smaller pits and dominated by fine scratches. Columbia Plateau cultures, who consumed large quantities of fish, may exhibit molar microwear more similar to the coastal groups than to

other foraging-hunting groups, because of contamination of the dried fish with particles of sand and wind-borne dust.

Recommendations for Future Work

1. When analyzing tooth surfaces with SEM, it is recommended that research protocols include provisions for controlling variation in the instrument stage geometry. Rigorously applied standardized procedures during the microscopic analysis phase of a microwear study will facilitate holding as many variables constant as possible. Especially important is the determination of the relative or actual angle of inclination of a wear facet or occlusal surface, and the ability to reference this angle to the axis of the electron beam column. The angle of inclination ('tilt angle') of the enamel surface relative to the electron beam axis should be kept as near to normal (perpendicular) as practical. A 'maximize and minimize' approach to the analysis is suggested. In other words, a happy medium should be struck which allows the producton of a high quality and detailed micrograph (maximize), while minimizing the skewing of feature dimensions. In any case, it is important to keep the degree of tilt away from normality within a reasonable range (15-25 degrees), and to standardize this as much as possible for each tooth specimen.

2. If quantitative data is collected from normal micrographic fields, it is probably not necessary to count additional features visible only on tilted companion micrographs for calculating grand total feature counts. The additional information provided by the unmeasured counts is insignificant, especially for relative proportions of features. For example, similar multiple comparison results were found for grand total feature counts, as for the regular feature count. In this case, only the level of significance was higher (0.01 versus 0.05, respectively). The elimination of this step also would produce a significant reduction in labor and time. As discussed in Chapter VII, however, the use of untilted fields to collect metric data from microwear features may obscure detail and limit the

detection of very fine features. Thus, information may be lost in the form of small features that are not visible and not measured. Therefore, it is probably better to rely upon moderately tilted micrographic fields when measurements of very small features are required by the research design, while still using a standardized protocol for controlling SEM stage geometry (as discussed above).

3. For dental microwear studies involving a comparative sample, and especially when funds and time are scarce, adequate information can be acquired from the analysis of only a single molar type. Such a procedure will allow the investigator to increase the sample sizes, while losing a minimum of information. If a choice of teeth is available, or in the case of very worn dentitions, the use of the second molar is recommended. In my study, significantly more variability within the data sets was explained for second molars than first molars (possibly because of the greater degree of wear on the first molars).

4. With regard to dental attrition, the wear scores could be used to calculate wear gradients and/or in linear regression analysis to plot the slope of the principal axis of the wear scores, as a means of predicting the intercepts for other age classes in the samples (Benfer and Edwards 1991; Scott 1979b). For example, the relatively wide spread of age at death for the individuals from the Harappa sample necessitated that the younger specimens be excluded from the multivariate analyses used in this study. With the principal axis technique, the teeth of juveniles could be included in the sample for wear analysis, and the calculated intercepts used in principal components and discriminant function analyses.

5. Tooth specimens should be examined macroscopically prior to microwear analyses. This allows detection of diagenetic and other post-mortem damage to the enamel surface of the specimen. Careful examination of the occlusal and facet surfaces may reveal undamaged areas that can still be of use in SEM microwear analysis. Additional examination of the enamel surface is required at high magnification under the SEM to ensure that the selected area is undamaged and 'typical' of microwear for other specimens.

Questionable specimens should be removed from the sample (Teaford 1988b).

6. Data should be derived from archaeological contexts on the size and morphological characteristics of dietary abrasive particle contamination (e.g., soils and grit particles derived from groundstone artifacts). The data should include samples of soils from living floors, work areas associated with groundstone tools used in food processing, and wood ash from pit hearths. Samples should also be collected of granular particles on the surface of or embedded in pestles, manos, metates, and mortars. These data could be collected in conjunction with botanical sampling for pollen, phytoliths, and other plant parts. Also recommended is the experimental use of prehistoric groundstone artifacts (or replicas) to process cereal grains, nuts, roots and other plant fibers to generate empirical data on the morphometric characteristics of abrasive particles derived from this use.

7. For testing microwear-generated hypotheses, palaeobotanical data should be collected for all plants, not simply the cereal crops, growing on or used at an archaeological site. This data should include silicon phytoliths and pollen, as well as seeds and pits from the plants.

8. Additional dental microwear analyses of South Asian skeletal samples would be useful for adding to the data base and dietary reconstruction provided by this study. This should include the collection of additional impressions of permanent molar teeth from Cemetery R-37 at Harappa, including adult individuals of both sexes. Of interest also are the microwear patterns on teeth from other South Asian and Middle Eastern cemetery sites, such as Inamgaon, Damdama, Shahr-i Sokhta, Kile Gul Mohammad, Mundigak, and Tepe Hissar.

9. The comparative dental microwear data base for prehistoric populations should be increased by including analyses of North American skeletal series. This has begun with ongoing analyses by the author of skeletal series from the Oregon coast (Pistol River site), Columbia River/Plateau (Wildcat Canyon site), and Great Basin (Gold Hill site). Also

recommended is the collection of quantitative dental microwear data from skeletal series of the Woodland cultural tradition, from the midwestern and southeastern United States. Such work will facilitate testing hypotheses generated from the previous qualitative microwear studies by Rose and colleagues, and from Teaford's quantitative work on the Georgia-Florida coast.

10. Other questions produced by my research are centered around the contributions that food characteristics, such as texture, hardness, and brittleness, dietary grit and abrasives from food processing technology make to the production of microwear features on tooth enamel. Answers to many of these questions can only be arrived at through the experimental study of human molar microwear, much as has been accomplished with living primates. To this end, it is suggested that ethno-anthropological research be conducted among caste and tribal groups from India, to collect dental microwear, anthropometric, ecological, nutritional and dental/gnathic data. Results of such an investigation will help to clarify the association between dental wear patterns, diet and culinary practices, and to provide functional analogues for reconstructing the diets of early hominid and prehistoric human populations.

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